INTERN EXPERIENCE AT
TECH TRAN CORPORATION
NAPERVILLE, ILLINOIS

AN INTERNSHIP REPORT

by

John Arthur Campbell

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ABSTRACT

Intern Experience at Tech Tran Corporation
Naperville, Illinois. (May, 1983)
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Chairman of Advisory Committee: Dr. Robert Young

This report presents a survey of the author's internship experience with Tech Tran Corporation during the period September 3, 1981 through April 30, 1982. The eight month internship was spent as an engineering intern with a small consulting firm specializing in high technology state-of-the-art manufacturing technology management and assessment. The intent of this report is to demonstrate that this experience fulfills the requirements of the Doctor of Engineering internship. The primary objective of the internship was to develop technical expertise in the field of industrial automation. Secondary goals were to improve oral and written communication skills and project mamagement techniques.

The three projects presented in this report met these objectives and goals. The major project was to develop a state-of-the-art assessment of robotics. This assessment was developed by surveying hundreds of robots users, manufacturers and reseachers, and undertaking a

comprehensive literature search on U.S. and foreign robots. The information was distilled into a professional managerial level report on robotics. The second project was to develop technical summaries and assessments of completed projects of the Army Missile Command's Manufacturing Technology Program. This was performed by reviewing project reports and interviewing government and contractor engineers throughout the country. The third project was to be an Associate Editor for Manufacturing Technology Horizons digest. This is a bi-monthly digest featuring major developments in manufacturing techniques and equipment. Short concise summaries for manufacturing processes were researched and developed through written correspondence and phone interviews.

The internship was an opportunity to use my engineering skills to learn about the robotics industry, and improve oral and written communication skills. Thus, objectives for the Doctor of Engineering degree were met and the internship requirement satisfied.

ACKNOWLEDGEMENTS

Many people are deserving my most sincere thanks because without their help the successful completion of the Doctor of Engineering program would not have been possible. I would first like to express my thanks to all the people that I worked with during the internship at Tech Tran Corporation for their friendship. I would particularly like to thank my internship supervisor, Mr. John Meyer for his guidance and help during the internship. I would also like to express my gratitude and appreciation to Mr. Ron Sanderson for his valuable advice while writing the robot report. Last, but not forgotten are both secretaries, Noreen and Claudia, whose tireless efforts on my behalf made it an enjoyable and successful internship.

I am certainly grateful to Dr. Robert E. Young, my committee chairman, for his valuable guidance and direction during my studies at Texas A&M University. I would also like to thank the other members of my committee and the entire staff of the Industrial Engineering Department for their support of my graduate studies.

Most importantly, I wish to thank my wife Patricia, and my son Keith, for the many hardships and sacrifices they so willingly made during my undergraduate and graduate degrees. Thank you for your love and understanding.

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DOCTOR OF ENGINEERING INTERNSHIP OBJECTIVE

Prior to the start of the internship, initial goals and objectives were drafted by the intern. These tenative objectives were reviewed and approved by the internship Advisory Committee. After beginning the internship, the final objectives and goals presented in Appendix A were developed by the intern, the internship supervisor and the committee chairman. The final objectives were submitted to the Advisory Committee for approval in January 1982.

The primary objective of the internship at Tech Tran Corporation was to develop technical expertise in the field of industrial automation. Specific interest of the intern was in the field of industrial robots. As a result of this interest, the major goal of the internship was to develop a state-of-the-art managerial level report on industrial robot technology. This report was to be accomplished by utilizing effective oral and written communication skills and good project management techniques. The report was to be accomplished with a minimum of time and money through utilizing sound engineering techniques in problem solving, project planning and financial analysis. The report was to perform a comprehensive assessment of the robotics industry including applications, costs, present and future development efforts, and forecasting the expected growth of the industry.

INTRODUCTION

This report describes the author's Doctor of Engineering internship with Tech Tran Corporation, Naperville, Illinois. Tech Tran Corporation is a small consulting firm specializing in information transfer and technology assessment. Its primary client is the government, however Tech Tran Corporation has worked for manufacturers, research institutes and other consulting firms. The internship began September 3, 1981 and ended April 30, 1982. The internship supervisor was Mr. John D. Myers, President of Tech Tran Corporation.

The intern reported directly to the President during the entire internship. This is not uncommon for a small and relativitely new firm. The President held responsibility for the overall direction and management of the company's activities, with particular emphasis on business development and managing the execution of client assignments. However during the intern's major project, the robotics study, daily coordination with Mr. Ron Sanderson, Senior Project Manager, was required. Because of Mr. Sanderson's experience, he was primarily responsible for assuring that the report was finished on time.

Working for a consulting firm usually provides an opportunity to undertake many and various types of projects. With a background in industrial engineering the intern was given two job functions. First as an Associate Engineer the intern was responsible for performing manufacturing research, technology assessments and forecasts, and benefit analysis for several Tech Tran Corporation projects. Secondly, as an Associate Editor the intern was responsible for researching and developing articles for Manufacturing Technology Horizons. This is a bi-monthly digest published by Tech Tran Corporation to identify new developments in various manufacturing areas which have potential to impact future production methods.

The internship however, was not limited to these two functions. Because of the nature and size of the business the intern had the opportunity to be exposed to many activities associated with managing a small consulting business. Several meetings were held with the President of the firm to discuss how the business was started, technical problems, managerial problems, expected growth, and future direction of the firm. Additionally, opportunities arose to participate in developing promotional letters and brochures for the digest and the robot report, selecting a computer/word processor system, and many other non-traditional engineering functions.

The internship was primarily focused upon three major projects. Figure 1 shows graphically the amount of time spent on each project. Approximately 60 per cent of the

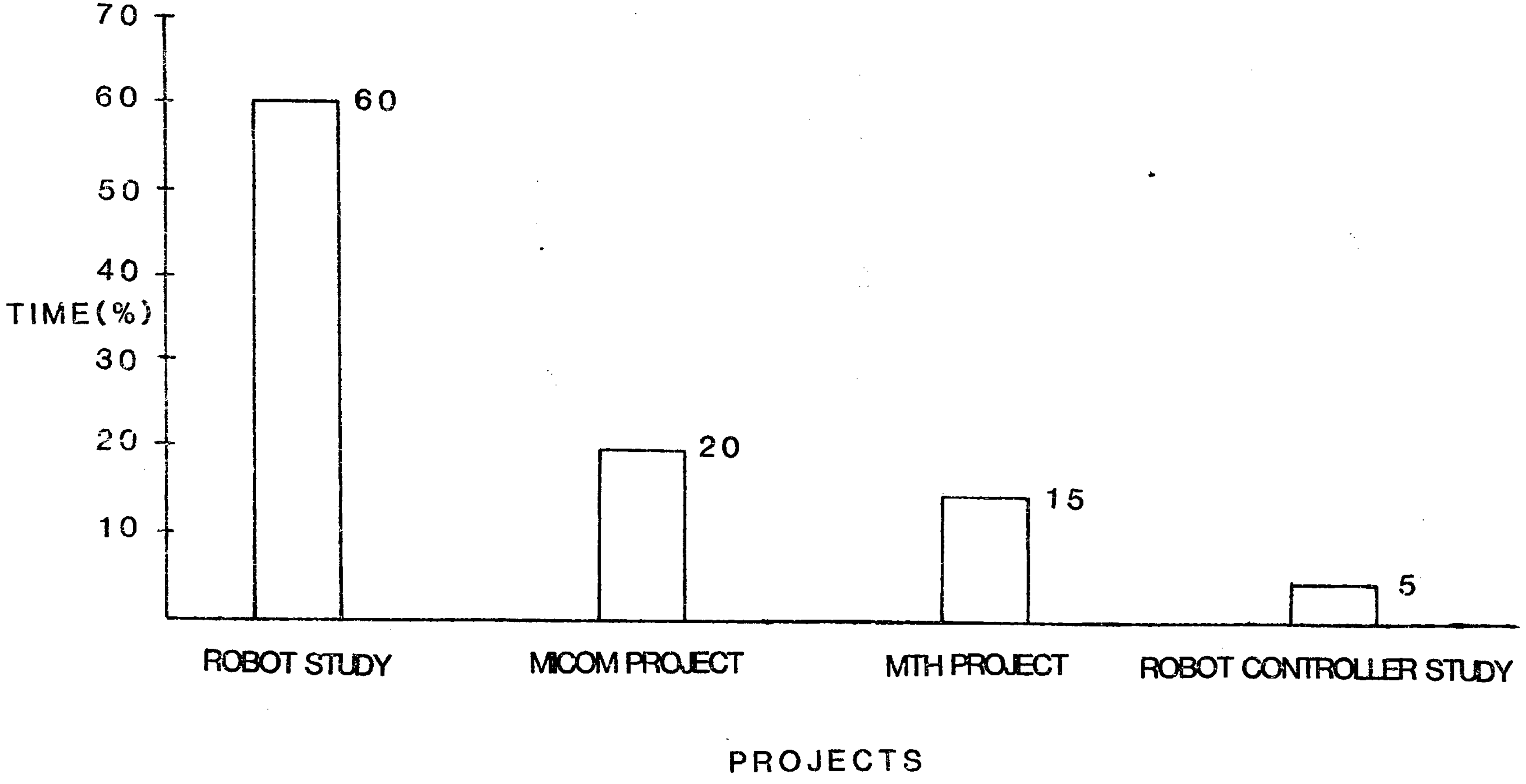

FIGURE 1: TIME ALLOCATION AMONG INTERNSSHIP PROJECTS

internship was researching, developing and writing the robotics study. This project was almost a full time effort for the first five months of the internship. Approximately 20 per cent of the internship was spent developing project summaries and benefit analysis for the Army Missile Command's (MICOM) Manufacturing Technology (ManTech) Program.

The final major project during the internship was researching and developing articles for Manufacturing Technology Horizons which accounted for approximately 15 per cent of the internship time. The intern worked on a fourth project for about one or two weeks. This project came from my discovering a lack of available information on robot controllers during the literature search and reinforced by inquires received after publishing the robotics report.

The above outline describes the major projects worked on by the intern. These jobs included many traditional and non-traditional engineering functions. All jobs stressed written and oral communication skills and good project management skills providing valuable training to the intern.

The intent of this report is to show that the internship with Tech Tran Corporation satisfied the internship requirements of the Doctor of Engineering

Program. This will be accomplished by demonstrating that the internship objectives have been met.

Following the next section, which describes the internship company, this report is divided into two main sections. The first section will identify the activities and efforts required to accomplish the state-of-the-art report on robotics. This section will show the importance of both oral and written communications skills. Comprehensive questionaires, letters of introduction, letters requesting information, and promotional literature were developed. In addition, many personal phone interviews were conducted to update and supplement the information required to write the robot report.

The final section of this report will detail the activities performed under the MICOM contract, the Manufacturing Technology Horizons digest and the robot controller study. This section will also show the importance of effective oral and written communication skills in attaining the information required to get the job done. It will also show the importance for Industrial Engineers to be knowledgeable in a diversity of different technologies. These sections will document that the intern's goals and objectives were fully accomplished.

THE INTERNSHIP COMPANY

Tech Tran Corporation is located in Naperville, Illinois, a small suburb approximately 30 miles west of Chicago. Tech Tran Corporation was incorporated in the State of Illinois in April, 1978, for the purposes of providing technical and management services in the area of technology transfer, particularly as it relates to manufacturing technology. Specifically, the Corporation specializes in services relating to the identification, evaluation and commercialization of new manufacturing processes, equipment and services. Tech Tran Corporation is particularly strong in the areas of long-range planning, technical management, and in new applications. The company also has a depth of capability in such areas as technology forecasting, market research and new product planning. Tech Tran Corporation offers its clients a number of services relating to technology management including feasibility studies, technology forecasts, technology transfer, market strategy and planning, producibility evaluation, trade-off studies, cost estimating, and modeling. Although emphasis is placed on high technology industrial products and processes, the Corporation is also capable of providing services to a diverse range of other industries.

Tech Tran Corporation has recently been preparing a series of manufacturing technology assessments and forecasts in such areas as robots, robot controllers, robot sensors, application of lasers in metal working and Computer Aided Design/Computer Aided Manufacturing (CAD/CAM). Additionally, during the internship Tech Tran Corporation introduced and is currently publishing Manufacturing Technology Horizons, a bi-monthly digest featuring new developments in manufacturing techiques, processes and equipment covering most industries. Tech Tran Corporation has also been developing an extensive technical library and, in particular, has developed one of the most complete reference libraries on robotics in the country. The company also subscribes to over 100 technical-and-business-oriented on-line computerized data bases and is in the process of developing several proprietary computerized data bases on manufacturing technology references, needs and development projects.

At the beginning of the internship Tech Tran Corporation had about twenty full-time employees. Supplementing these full-time employees the company had approximately twenty part-time consultants located throughout the country. Most of these employees were located at Tech Tran Corporation's corporate headquarters in Naperville, although several were located in Washington, D.C., Dayton, Ohio, and Huntsville, Alabama. Tech Tran

Corporation's staff has extensive backgrounds in industrial, mechanical and electrical engineering disciplines, production operations and manufacturing research. In addition to the engineers, Tech Tran Corporation employed two secretary/administrative assistants, a managing editor for Manufacturing Technology Horizons, and a graphic artist. Figure 2, is an organizational chart for Tech Tran Corporation.

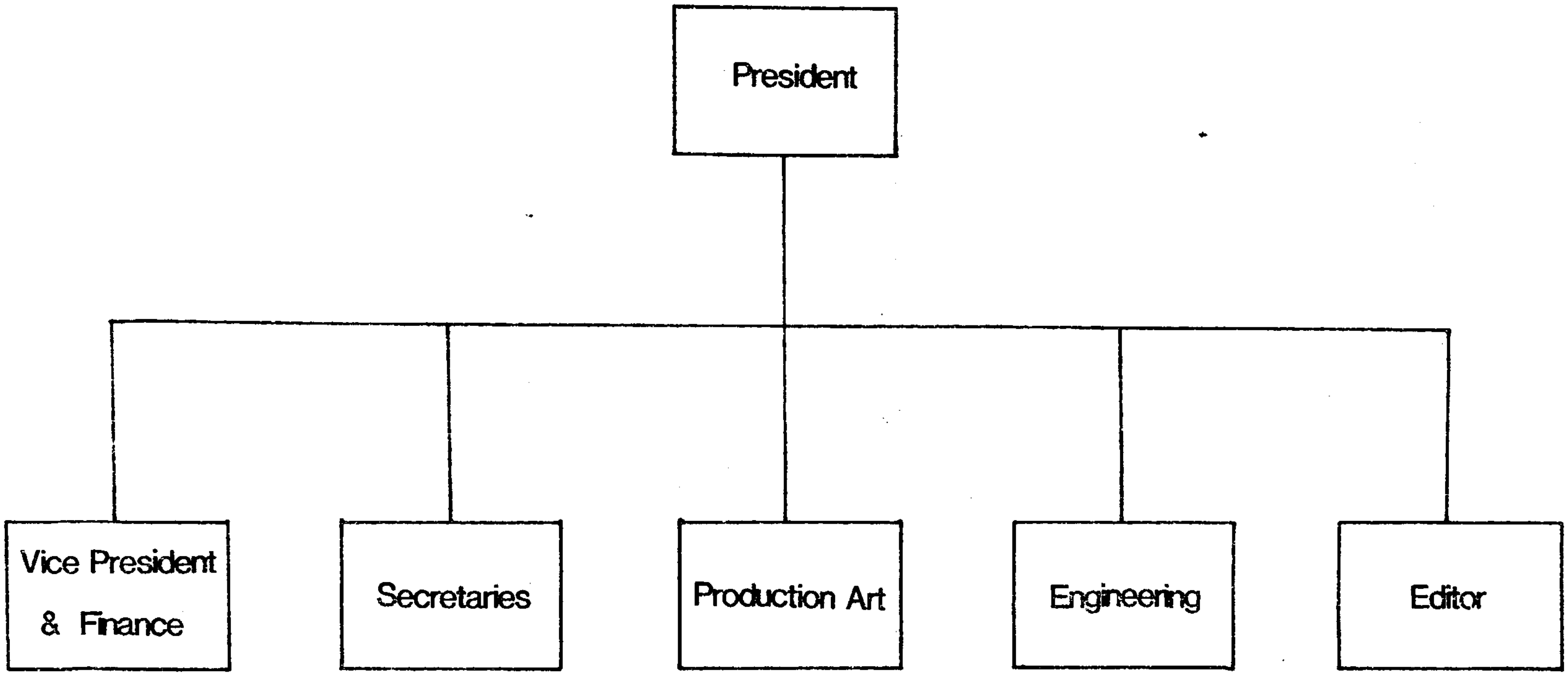

FIGURE 2: TECH TRAN CORPORATION'S ORGANIZATION CHART

CHAPTER ONE

While at Tech Tran Corporation the intern worked on three major projects and began a fourth prior to the internship being completed. This section will describe the major project accomplished during the internship and the following 'section will discuss the other projects accomplished while at Tech Tran Corporation. This section describes the effort involved in developing, writing and publishing a state-of-the-art report on robotics. It describes the methodolgy used to assure that the data collected was the most current information available, that a very comprehensive literature search was conducted, and that the accurate tabulation and analysis of the data collected was performed.

The original purpose of the robotics report was to help introduce the Manufacturing Technology Horizons digest. Tech Tran Corporation's initial intent was to give a copy of the robot report to those subscribers who prepaid a subscription to Manufacturing Technology Horizons. Tech Tran Corporation also planned to sell copies of the report but did not expect to recover the full developing and publishing costs by marketing the report alone. However, because of the interest generated by the report, Tech Tran Corporation has developed and mailed additional promotional and sales literature. The report turned out to be a far greater effort and expense than originally planned. Over six man-months of engineering hours were expended developing and writing the report. Additionally, many hours and dollars were expended on typing, editing, graphics development, mailing and printing of a report that almost doubled in size over initial expectation.

The subject of robotics was chosen for several reasons. During an interview with Mr. John Meyer prior to the internship, mutual interests were expressed in the field of automation and specifically developments in robotics. The topic of robotics has been an extremely high interest subject for the last several years, not only in the U.S. but other countries as well. This interest is shown by the news media, both written and broadcasted, where many articles on robotics have been recently presented. However, many of these articles were very general in nature and usually publicized by the robot industry. Over the last several years, two or three good reports have been published on robots. These reports are typically technical in nature, are specialized or did not cover the total subject on robotics, and particularly have not included experiences of robot users.

Tech Tran Corporation's approach was to try to fill the gap missing in robotic literature. Tech Tran Corporation wanted to prepare a comprehensive unbiased report using the latest available data written in a semi-technical language for the engineering manager. The major features of this report would include an introduction to industrial robots including terms and definitions, types of robots and their capabilities, current and future applications, cost and benefits of robots, and future direction of robots. Prior to this report there was no single document available anywhere that supplied this information.

The robotics report was a joint effort shared primarily by Mr. Ron Sanderson, Tech Tran Corporation's Senior Project Manager and the intern. It was Mr. Sanderson's and the intern's responsibility for writing the report and assuring that it was finished on time and ready for mailing with the first issue of Manufacturing Technology Horizons. However Mr. Meyer was actively involved in reviewing, editing and developing information sources for the report.

Tech Tran Corporation had begun researching and collecting articles on robotics prior to the official start of the internship. Several Tech Tran Corporation employees had begun literature searches of the NASA/Huntsville, Alabama, Washington, D.C. and Dayton, Ohio area libraries. Tech Tran Corporation had also ordered several robotics reports that were presently being marketed by other consulting firms. Additionally, in order to obtain the most current information and to develop important personal contacts in the field of robotics, the intern spent a week attending several meetings in the Washington, D.C. area.

The first meeting attended was a workshop sponsored by the Office of Technology Assessment for the 97th Congress of the United States. This was an exploratory workshop on the social impacts of robotics and the participants were leading experts in their fields. Influential representatives of the computer, automobile, aerospace, robotics and other manufacturing industries were participants including presidents and vice-presidents of some companies. Other participants included university, government, and union representatives. This was a one day workshop which had the following goals:

* assess the current and likely future state of robotics technology;
* examine the structure of the robotics market, including domestic and foreign users and producers;
* determine how robotics relates to other manufacturing technologies such as computer-aided design and flexible manufacturing systems; and,
* determine whether significant Federal policy issues were likely to be raised by the expected growth in industrial robotics.

Four background papers were developed and presented at the workshop to help lead the discussions. The first paper presented an indepth look at the Japanese robot industry and made several comparsions with the U.S. industry. The second paper discussed many of the technical problems with today's robots, who and what kind of research is being done in the U.S. and also looked at the future of the robotics industry. The third paper discussed productivity issues, whether or not robots will decrease manufacturing cost and can robots improve U.S. international competitiveness. The fourth paper discussed the status of U.S. manufacturing, analyzed the current and potential uses of robots, looked at the future robot market and its impact on manufacturing operations and discussed financial incentive programs which could stimulate more growth in the robot industry. These reports and the conference proceeding can be obtained from the U.S. Government Printing Office, Washington, D.C.

The second meeting was at the National Bureau of Standards (NBS) located near Washington, D.C. The purpose of this meeting was to learn what type of robotics research the NBS was presently conducting, what they have done in the past and what future direction they are planning. The intern's host was Mr. Bradford Smith, Group Leader of the Manufacturing Systems Group, NBS; who introduced Mr. James Albus, Acting Chief of the Industrial Systems

Division, NBS; and Mr. Robert Hocken, Chief of the Automated Production Techniques Division, NBS. These gentlemen are responsible for the majority of the NBS's robotics research effort and are recognized as leaders in the field of robotics research.

A tour of the NBS research facilities was conducted by Mr. Smith which included areas of industrial automation. However, highlighting this tour was their robotics laboratory where technicians were working with a Unimation PUMA robot and a Stanford Arm robot. They were working on a robot vision system and methods of assuring robot safety. NBS is one of the very few research organizations investigating robot safety issues. NBS has also conducted much research in force and proximity sensing for real-time feed-back and control and has developed a real-time hierarchical control methodology for robot systems.

Working as a team the three gentlemen are trying to make the NBS the leader in robotics research. They have successfully planned, designed and are now implementing a modern robotics research facility. Using a budget of several million dollars they are in the process of developing a completely flexible automated production line. This line will use several different types of robots, NC machines, and material handling equipment.

The line will also be available to private industry, government, university and other personnel to perform research and development tasks.

The third stop on this tour was a visit to the Pentagon to see Brigadier General Connelly, USAF, Chief of Air Force Plans for Contracting and Manufacturing. General Connelly expressed much interest in robotics and discussed the military use of robotics and gave several examples of their use in the aerospace industry. He presented his views on where robotics would be used in the future, particularly the military, and expressed a concern for the lack of automation in the aerospace industry. He also said he had just returned from a trip to Japan. While there he had toured several leading robot manufacturing plants and several companies using robots. He said that he was very impressed with the extent of automation in Japanese industries and the increasing number of robots being used. Finally, he indentified the Material Laboratory's Manufacturing Technology Division located at Wright-Patterson Air Force Base, Ohio as a source for much information on what the Air Force is doing with robotics.

Several other trips were taken during the writing of the report to assure that the most current information on robotics would be available. These trips included attending several technical shows and conferences in the

Chicago area featuring robotics. An additional trip was taken to the Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio to talk with Dr. Vince Russo, Chief of the Manufacturing Technology Division. He introduced many of his department chiefs and provided the opportunity to discuss many of the Air Force's Manufacturing Technology Programs including several in production automation and robotics. These trips were used to obtain information that would make the report as current as possible.

One of the first tasks that Mr. Meyer requested was to develop a schedule for accomplishing the report. The schedule was to be based upon a 100 page report and the mailing of only one questionnaire, that to robot users or potential users. Since the report was to be mailed with the January issue of the Manufacturing Technology Horizons digest, Mr. Meyer imposed an early December completion date for the report. Based upon these constraints, Mr. Sanderson and the intern developed a schedule which identified the key milestones required to accomplish the report. Everyone agreed that the schedule was optimistic and had little, if any slack time incorporated in it. This schedule is included in Appendix B. The last section of the report was finished December 22, 1981 and the completed report was sent to the printer on January 4, 1982. The schedule slip of approximately

30 days was as a result of several factors. First, it was felt that to make the report unbaised, additional questionnaires had to be sent to robot manufacturers and researchers. Second, the report page limit began growing considerably because of all the information available. Third, because of more important business priorities, many of the reviews and editing cycles took longer than expected. However, the report was received from the printer prior to the digest and both mailed during January, 1982 as promised.

While developing the schedule, Mr. Meyer requested that a synoptic outline of the report be developed. He feels that this is one of the most important steps in assuring that everyone understands what will be contained in the report and if it can be finished on time. An indepth outline was developed for the robotics report that identified each chapter title, each section and discussed each topic covered by the report. Ideas and drafts for many of the charts, tables and pictures included in the final report were created during the development of the synoptic outline. During the development of this outline it was decided that two additional questionnaires were needed to be more objective in writing the report. Finally this outline was reviewed, edited and accepted by Mr. Meyer and an approach for developing the report was agreed upon by all involved.

This approach included the continued gathering of information on robotics locally through Tech Tran Corporation employees and other contacts thoughout the U.S. It was also decided that three questionnaires were to be developed, one for robot manufacturers, one for robot researchers and one for robot users. Because of the difficulty of'obtaining information by mailed questionnaires, it was decided to make these as personal as possible. This required obtaining many individual names of people working with robotics from whatever sources were available. An extreme amount of work went into developing these questionnaires and mailing lists to assure an adequate response rate. The first questionnaire, which was for the robot users, was by far the most complicated and difficult of the three. The other two together took significantly less time to develop than the first.

Approximately 300 questionnaires were mailed by Tech Tran Corporation and almost half were successfully returned. The staff at Tech Tran Corporation were relieved and happy that the return rate was so high. This was a major step in attaining fresh new information for the report and gave renewed confidence that industry was interested in robotic developments. Typical good questionnaires are often considered successful if they attain a return rate of 10-15 percent, so it appears Tech Tran Corporation had good reason to be happy. Tech Tran

Corporation's return rate of around 40 percent was the result of an extremely good incentive, which is discussed later, for returning the questionnaire and emphasizes industries interest in robotics.

During the development of this report and as the schedule in Appendix B shows, several tasks were ongoing simultaneously. The first month activities were primarily involved with developing mailing lists and questions, designing the questionnaires, and conducting literature searches. Although robotic articles were constantly being sought, most of the information was obtained within two months from the start of the internship. Many of these articles contained the names of individuals that were used to comprise the mailing lists.

Developing a mailing list such as the ones required for this survey is not as easy as one might expect. First you cannot purchase a list of robot users. Secondly, the robot industry is expanding so rapidly that it is difficult for any organization to keep an up-to-date list of robot manufacturers, researchers or users. Third, there are some companies and organizations that do not want it known that they are using robots or performing robotics research for several reasons. Many robot users are in a very competitive business and are seeking ways of remaining competitive. Robotics can give them a competitive edge. Consequently, they don't want it generally known that they are using robots. Also many users are being overwhelmed by inquiries and requests for information on their particular robot applications. This has become such a problem that many users now require the robot manufactures to sign an agreement not to release their names. However, a list of over 300 robot users or potential users, manufacturers' and researchers was obtained for the survey.

Several sources were used to obtain the mailing lists. One of the easiest lists to obtain was that of the robot manufacturers. There are several organizations that try to keep a current list of robot manufacturers. The most noted are Robot Institute of America, a part of the Society of Manufacturing Engineers, and the Robotics Industry Directory, published in California. However these lists are usually only published once or twice a year and with an industry growing as fast as robotics, the list can quickly become incomplete. Therefore, additional searches were conducted of newspapers, magazines, news releases and other advertisements in order to obtain the most current list possible at the time of mailing the questionnaires. This resulted in a list of over 50 manufacturers.

A similiar process was used to obtain the list of robot researchers. A list of researchers can be obtained from the same organizations that compile lists of manufacturers. However as noted above to obtain the most current list available required searching much of the published literature and interviewing many of the recently developed personal contacts. A list of appoximately 55 research organizations including government, private and university laboratories comprised the list.

The largest and the most difficult list to obtain was that of the robot users and potential users. The literature search indentified that there are somewhere between 300-400 firms using robots. Because of the cost of surveys and the difficulty of obtaining the names of robot users, Tech Tran Corporation decided that it was only feasible to survey about 200 firms. These names were obtained from several sources. Robot manufacturers supplied the names of many satisfied customers. Also, names of users were obtained from companies advertising and promoting the fact that they are using robots. Other companies publish technical papers through organizations such as Society of Manufacturing Engineers describing their experiences with robotics. Through these sources and a very detailed and comprehensive literature search, over 100 names of individuals and companies were obtained. The remainer of the list was obtained through an analysis of several industries to determine which was the primary user of robots. It was determined that metal working plants are the largest user of robotics in such application as welding, material handling and machine loading. Nearly one-half of all robots are being used by the automobile industry and their single most important application is spot welding. This data was then used to select appropriate plants from industry trade registers. The total list of users and potential users consisted of over 200 companies of various industries with the automobile industry being the largest surveyed. These industries included the Aerospace, Automobile/Truck, Heavy Equipment/Tractors, Farm Equipment, Food, Textile, Foundary/Casting and Machining companies. Each list was then carefully reviewed and checked to insure that no more than one questionnaire went to the same address.

Designing the questionnaire was a true learning experience. There are several constraints that must be balanced in order to achieve an effective questionnaire. The most important is to assure that the right information can be obtained from the questions asked. In this case Tech Tran Corporation wanted as much information as possible so that future reports and articles could be written. With this in mind and the synoptic outline, many questions were developed and the questionnaires began taking shape. Other important constraints that were considered in developing these questionnaires are:

* How much time does it require to fill out;

- how difficult is it to read, understand and answer the questions;
- how do you ask for company sensitive information; and
- what incentive do you give for responding.

Achieving a balance between these constraints was a very difficult task. Finally, after several edits and rewrites the user questionnaire shown in Appendix C was accepted by Mr. Meyer. It requires about 30 minutes to fill out, the questions are simply worded, and the majority of the answers can be filled in by either checking, inserting numbers or through one or two word answers. The approach to company sensitive data was to limit the number of questions and to put a non-disclosure guarantee in the introductory letter (see Appendix D). After many discussions, it was decided to offer each respondent a free copy of the robot report and a one year free subscription to the Manufacturing Technology Horizons digest. Several other incentives were discussed including giving either the report, the digest, or a summary of the report, but these were not selected because of the concern for getting an adequate response rate. After these decisions were made, the type and quality of paper, envelopes, including return envelopes were chosen, and the mailing class (1st class) decided.

Using the user questionnaire as a sample the manufacturer's and researcher's questionnaires were developed. The experience gained on the user questionnaire greatly reduced the time required to design the next two questionnaires, also contained in Appendix C. Similiar decisions, including formats, incentives and introductory letters, were used in developing these questionnaires. A sample introductory letter is contained in Appendix D.

Soon after mailing these questionnaires Tech Tran Corporation began receiving inquiries about the report. Many of the inquiries were from individuals completing the user questionnaire who were not presently using robots but wanted to receive a copy of the report. Many of the researchers wanted more information about the report and some wanted an advance copy or draft. A few robot manufacturers inquired to see if they were being included in the report and some supplied photographs for inclusion. The interest expressed by these inquires was encouraging to the authors of the report. Many of these inquires supplied up-to-date information which was included in the report.

Because of this interest Tech Tran Corporation decided that it was time to develop promotional literature to advertise the report. A sample of this literature is contained in Appendix E. Tech Tran Corporation expended a significant amount of time and effort to assure that this literature would have the highest appeal and quality possible.

As the questionnaires began to return, compiling the information became a difficult job. Tech Tran Corporation mailed a total of over 300 questionnaires and had a response rated between 30-40 percent. The three questionnaires consist of 125 total questions, which relates to over 4000 responses from all three questionnaires. These responses were tabulated and analyzed by hand in order to save time and money. Some interesting, unique and accurate facts were concluded from these surveys. The data obtained in the three questionnaires and included in the report separates this report from other robot reports. Several important facts and suspected trends developing in the field of robotics were verified by the questionnaire data.

Many of the problem areas concerning robotics are perceived differently by the three groups surveyed. Not all users, including researchers, are satisified with present day robots. Many robots are too expensive, not fast enough, not accurate enough, and reliable enough for the manufacturing environment. Many users report that the average cost of an installed robot is more than what the manufacturers report and the payback period is longer. The users also report that the robot base price can be typically one-half of the total installation cost of a robot system. In addition, the systems reliability is less than reported by robot manufacturers. As much information from the questionnaires as possible was included in the report, however many other sources were also included.

An ongoing effort throughout the development of the robotics report was seeking and reviewing new robotic articles. The majority of the information that was used as the foundation of the report was collected during the first few weeks of the internship. Several trips to the Chicago Public Library resulted in a large number of robotics articles. Also other Tech Tran Corporation engineers were performing literature searches in several private industrial libraries in the area. Computerized data base searches were conducted and many articles and reports were purchased from the National Technical Information System. Many good reports were obtained from the Office of Technology Assessment, National Bureau of Standards and the Society of Manufacturing Engineers. Tech Tran Corporation had also obtained documents on foreign robots but this information was not included in the report because of increasing its size beyond what was planned. Several articles discussing Japanese robots and markets were obtained from the Japanese Foreign Trade Center located in Chicago. Information on the British robotic effort was obtained through a literature search of the Library of Congress, Washington, D.C. and Tech Tran Corporation was able to obtain and have translated a few Russian robot articles. Some of this information was included in a Manufacturing Technology Horizons digest article.

Toward the middle of the second month of the internship, a significant amount of robotics literature was being collected at Tech Tran Corporation. It was becoming difficult to review, sort and classify each and every article. To help solve the problem of having an over abundance of information, a simple matrix form was developed to classify each article. In one column on the form each topic in the robot report was listed. Each article obtained from the literature search was then listed in a row on the form so that a cross reference between each could be made. Once this classification scheme was developed, each topic in the robot report could be written by reviewing only a few articles that were pertinent to that particular topic. Similar matrices were used to classify and analyze the data received in each questionnaire and to compare answers from all three groups.

The actual writing of the robot report (see Appendix F) took approximately six weeks from the start until the final revision was completed. It took the efforts of two engineers working almost full time to accomplish the task.

The original plan was for a 100 page report to be finished the first of December, 1981. The final draft turned out to be over 200 pages and was finished around the middle of December, 1981. After a significant amount of editing, the final report consisting of 167 pages was delivered to the printers around the first of January, 1982.

This report is one of the first attempts to survey a significant number of robot users, researchers and manufacturers. No other report could be found that reported the experiences of such a large number of robot users. This report was also the first attempt to compare a large number of users experiences with what robot manufacturers were reporting. Much of the information present in the report is original data developed by Tech Tran Corporation from the questionnaires. The report has received wide spread acceptance and acclaim from both the academic and industrial community. Appendix G contains examples of reviews which have appeared in various technical journals.

CHAPTER TWO

Chapter One described the major project accomplished by the intern at Tech Tran Corporation. Chapter Two will describe three other projects accomplished by the intern which help to satisfy the objectives and goals of the internship. These three projects are 1) the Army MICOM contract, 2) the Manufacturing Technology Horizons digest, and 3) a proposed study on Robot Controllers.

Missile Command Project

Tech Tran Corporation has had an ongoing contract with the Army Missile Command's (MICOM) Manufacturing Technology (ManTech) Division, Huntsville, Alabama for several years. MICOM is responsible for the Army's missile development program. The ManTech Division at MICOM is responsible to find and fund projects that will reduce the cost and increase the producibility of missiles and their components. ManTech projects are often referred to as "seed projects". This means that the Department of Defense (DOD), in this case the Army, awards small contracts to improve manufacturing processes, techniques, and equipment used on specific military projects.

One of Tech Tran Corporation's tasks is to review all MICOM ManTech projects and develop two/four page summaries, identify spin-off projects, rank the importance of the projects, and perform cost/benefit analysis on each project. MICOM has many uses for this information and presently does not have the manpower to develop it themselves. One such use is to provide historical data on old completed projects in which the final reports are no longer available. Another use is to provide short, concise, and accurate information on a large number of projects in order to better manage these projects. Also, these summary reports are to be used to futher identify and track "successful" ManTech projects. The term successful as it applies to a ManTech project usually means that the effort accomplished under the contract is incorporated into a missile or other military system. Utilizing this new technology typically results in an increase in reliability, reduction in cost, and/or increased producibility of the system. The more successful projects are monitored closely by MICOM and used to promote the ManTech program in order to maintain and increase its DOD funding level.

For effective management Tech Tran Corporation classified the Army's ManTech projects into four areas; Metals, Non-Metals, Electronics, and Test/Inspection. The intern was assigned projects in all but the metals area. The following paragraphs presents a few examples of typical projects that the intern developed for MICOM.

Sample projects in the electronic area included developing high current density cathodes for electron tubes. Thin film field emission cathode technology was used to produce a device capable of operating at a current density in excess of 10 Amps/cm^2. Another high technology project was improving silicon target vidicon tubes used in missile seekers and other electro-optical devices. This project improved manufacturing techniques and produced a much more rugged ceramic tube instead of the more common glass tube. Several other projects in the electronics area included circuit board manufacturing, component mounting/insertion, improved flexible circuits, and module encapsulation.

In the non-metals area, projects included developing lightweight plastic missile components. One project produced reinforced plastic molded missile airframes at much less weight and cost as compared to their metal counterparts. Another project was to develop a glass-reinforced composite for lightweight man-portable missile systems. Several glass fibers and process parameters were investigated under this project.

In the test/inspection area several projects evaluated non-destructive testing and non-film x-ray techiques to inspect missile components. These projects were looking for low cost reliable methods for inspection of high volume missile components.

Appendix H contains a few of the intern's ManTech project summaries presented to MICOM by Tech Tran Corporation. Prior to the completion of the internship, Tech Tran Corporation requested that the intern provide a short evaluation on each project's worth (see Appendix I) and to rank each project (see Appendix J) according to how effectively it met the goals of the ManTech Program.

The MICOM project is a good example of what can be expected of today's Industrial Engineer. The diversity of projects assigned can be typical of any industrial engineering job today. The need for knowledge and experience in a wide variety of technologies became readily apparent while at Tech Tran Corporation. Because of today's highly competitive business environment and emphasized by the short duration of the internship, Tech Tran Corporation expected immediate productivity from the intern and all employees. There was little business time available for additional training in new technological areas. Each MICOM summary was expected to take no more that 2 1/2 days for a final typed version. At times, because of the subject area and one's experience, this could be a very difficult but not an impossible task.

These ManTech project summaries were usually developed through a four step process. The first step was to read the final project technical report, if it was available.

These reports varied from 80 to 500 pages and often the quality of the information varied equally as much. MICOM requested that Tech Tran Corporation provide the project summaries in a format which included a background, objective, accomplishments, and benefits area. Typically the final reports included information on the project objectives and accomplishments but very seldom had information on background and benefits.

As a result the second step was to call the MICOM project engineer to see what information he could provide. However since several of the projects were 10 to 15 years old, it was often difficult to get little more than a contractor's name and project engineer. With the more recent contracts, the MICOM personnel were usually able to provide background information, contractors telephone numbers and contacts with other military programs using or evaluating a ManTech development.

Step three involved telephoning the contractor's project engineers and other contacts who might be using the ManTech developments. Discussions with the contractor's project engineers usually determined whether or not the technology was being used or if some spin-off program had resulted from the ManTech project. An unsuccessful project usually was finished, except for the write-up, at this step.

A successful project could entail telephoning several more companies and project engineers to identify what programs were using this technology and what kind, if any, benefits and cost saving were being realized. If possible, detailed cost saving information had to be obtained for each program using the ManTech development. This data and information were important in determining and evaluating benefits of the program. The program's benefits, particularly identifiable cost saving, were one of the most difficult to assess. Sample MICOM summaries are contained in Appendix H.

Finally after all reasonable contacts had been exhausted, step four involved organizing the data into a format acceptable to MICOM. This included the two/four page summaries, a program effectiveness report, detailed cost saving information, and another short summary MICOM used to develop a Manufacturing Technology data base on all projects.

Manufacturing Technology Horizons

Manufacturing Technology Horizons (MTH) is a bi-monthly digest on new production technology. Tech Tran Corporation published its premier issue in January, 1982. The digest is written for manufacturing and engineering executives and features short, concise and unbiased articles on current developments which are likely to have a major impact on future manufacturing operations and productivity. Each article describes key technical features, assesses the commercial potential, identifies the state of its development, and provides the researchers/developers name and telephone number.

It was the intern's responsibility to develop and write articles appropriate for MTH. This required developing a total of 40 to 60 articles every two months in addition to the special feature articles which were included in each issue. These articles were developed from several sources including reviewing technical magazine articles, news releases, advertisements, technical conferences, and through personal contacts with engineers and scientists. Tech Tran Corporation's sources were international in scope and included government laboratories, research institutes, equipment manufacturers, trade and professional organizations, private manufacturers and universities.

Appendix K contains a sample of the first MTH digest published and articles developed by the intern for the May/June, 1982 issue. Appendix L contains samples of some of the many pieces of promotional literature and news releases that the intern participated in developing with other Tech Tran Corporation staff.

Robot Controller Study

One of the many high technology studies in which Tech Tran Corporation has had plans to perform in addition to the robotics study was one specializing in robot controllers. The need for such a document, that would consolidate information on the various types of controllers used throughout the industry, has been recognized by Tech Tran Corporation for sometime. However, as of yet such a document does not exist and it appears that no other organizations are in the process of writing such a document. Tech Tran Corporation received many telephone inquiries from purchasers of the robot report requesting additional information on robot controllers. Many of these inquiries indicated a need for a semi-technical document on robot controllers. They also indicated their willingness to purchase such a document if written in a similiar form as the robot report. Because of these and other business factors Tech Tran Corporation decided to investigate further a robot controller study.

The intern was chosen to develop the robot controller report because of the experience and contacts gained on the recently completed robotics report and because of the expressed goals of the Doctor of Engineering internship objectives. The intern was asked to first develop an outline for the report indentifying each chapter and to describe the major topics covered in each chapter. In order to accomplish this, a preliminary literature search of Tech Tran Corporation's robotics library was conducted. It was soon realized that very little information, particularly technical information, was available on robot controllers. Even the promotional literature provided by the robot manufacturers had very little information about their controllers. In order to obtain as much information as possible on the subject, the intern used the Tech Tran Corporation computer to perform a data base search specifically on robot controllers. Through this search, which included some European data bases, enough information was obtained to begin outlining the robot controller report.

A detailed outline of the robot controller report was presented to Tech Tran Corporation. Included were examples of tables, graphs, figures and pictures which might be included in a final report. However because of the short time remaining for the internship and the expense of developing a report similiar to the robotics study, Tech Tran Corporation decided to forego the immediate writing of this report. Instead Tech Tran Corporation decided to put together a consortium of interested companies that would help finance this and another similiar study on robot sensors. This was currently in preparation at the end of the internship.

CONCLUSIONS

This report describes the major tasks accomplished by the intern during the Doctor of Engineering intership at Tech Tran Corporation. Tech Tran Corporation is a small engineering consulting firm specializing in technical and management services in the area of technology transfer, particularly as it relates to manufacturing technology.

The major objective of the internship was to develop experience in the field of industrial automation with specific interest in the field of robotics. Good project management techniques utilizing effective oral and written communication skills would play a major role in developing this expertise. As this report identifies, these objectives were met through undertaking several major projects during the internship.

The first project and the primary objective of the internship was developing a state-of-the-art managerial level report on industrial robot technology. It was through the development of this report on robotics (see Appendix F) that the major objective of the internship was accomplished. Information was obtained from a comprehensive literature search of several computerized data bases and libraries throughout the United States and Europe. Additionally, robot manufacturers, users and researchers were all surveyed to obtain new and unique data to include in the report. Finally, several interviews were conducted with robotics researchers and manufacturers to obtain the most current information possible. This information and data were analyzed and assimilated into a professional level report which has been distributed throughout the United States and Europe. The report focuses upon robot components and performance characteristics; U.S. robot manufacturers, models and services; present and future research efforts, organizations, and industry trends; and implementation and application engineering for installing robot systems.

Several other projects accomplished at Tech Tran Corporation also contributed to satisfying the objectives of the internship. These projects required the use of many of the engineering skills acquired during my working career and at Texas A&M University. The technical courses taken at Texas A&M University provided the required background to understand many of the projects accomplished at Tech Tran Corporation. Working as an Associate Editor for the Manufacturing Technology Horizons digest required assessing many new manufacturing/production developments. Effective oral and written skills were applied in interviewing the responsible engineers to obtain the necessary data required for the short concise articles in Manufacturing Technology Horizons. These same skills were heavily relied upon while working on the Army Missile

Command project. Both oral and written communication skills played an important part in reviewing and performing benefit analysis on the Manufacturing Technology projects.

It is the conclusion of this report that the final objectives and goals of the Doctor of Engineering Internship at Tech Tran Corporation were successfully fulfilled. It is also the opinion of Mr. John Meyer, the intern's supervisor, that all internship objectives and goals were fully achieved as stated in his final letter report contained in Appendix M.

APPENDICES

APPENDIX A

FINAL INTERNSHIP OBJECTIVES

DOCTOR OF ENGINEERING INTERNSHIP OBJECTIVE

BY

JOHN A. CAMPBELL

TECH TRAN CORPORATION, NAPERVILLE, ILLINOIS

SEPTEMBER, 1981 - MAY, 1982

OBJECTIVE

The primary objective of my D.E. internship is to develop technical expertise in the field of industrial automation. The improvement of both oral and written communication skills shall play a major part in developing this expertise. Good project management skills shall be required to develop and complete technical projects in a minimum amount of time. These objectives shall be realized by applying sound techniques in problem solving, organizing, project planning and financial analysis.

My specific interest and goal of this internship is to become technically competent in the field of robotics. This will include knowledge about the robot industry, robot applications, and all aspects of robotics including mechanical and electrical designs, software controls and interfacing capability of robotic systems.

The major project undertaken during this internship shall be to develop a state-of-the-art managerial level report on industrial robot technology. Information on the field of robotics shall be gained from comprehensive literature searches, surveying robot manufacturers, research organizations and robot users, and through personal discussion/ interviews with robotics experts. This report will identify robot manufacturers, their models and present robot applications. It will discuss major research efforts in robot capabilities and application, and assess what new technological developments are required for future robotics systems.

APPROVED BY: January 27, 1982

Robert E. Young
Dr. Robert E. Young, I.En.
Committee Chairman

John A. Campbell
John A. Campbell
Doctor of Engineering Intern

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Dr. Robert Whiting
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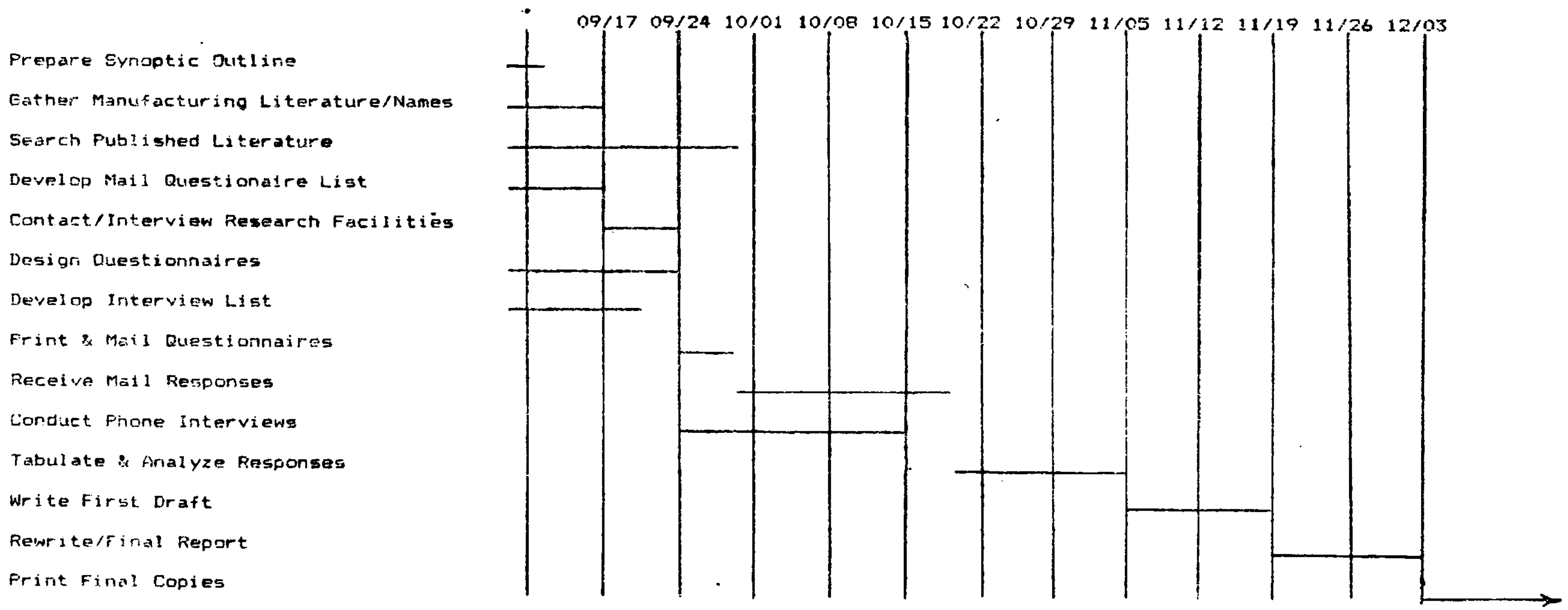
Dr. Micheal J. Ash
Graduate College Representative

APPENDIX B

ROBOTIC REPORT SCHEDULE

ROBOTIC REPORT SCHEDULE

Date: September 8, 1981



APPENDIX C

ROBOT REPORT SURVEY QUESTIONNAIRES

RESEARCH ORGANIZATIONS QUESTIONNAIRE

INDUSTRIAL ROBOT QUESTIONNAIRE

I. BACKGROUND

The following questions concern your organization and the nature of the research in which you are engaged.

1. What is the total annual research budget for your organization?

☐ $ 0 - 100,000
☐ $ 100,000 - 500,000
☐ $ 500,000 - 1 Million
☐ $ 1 Million - 5 Million
☐ Over $ 5 Million

2. Please indicate the primary affiliation of your research organization;

☐ Government
☐ Industry
☐ University
☐ Independent
☐ Other:____________________

3. In what areas of automated manufacturing is your organization currently conducting research?

☐ Robotics
☐ Computer aided design (CAD)
☐ Computer aided manufacturing (CAM)
☐ Computer aided testing (CAT)
☐ Other ____________________________
☐ Other ____________________________

(If you are not engaged in robotics research, proceed to question 15)

4. What is your annual robotics research budget?

$ ____________________

5. How many professionals are engaged in robotics research in your organization?

☐ 0 - 5
☐ 6 - 10
☐ 11 - 20
☐ Over 20

6. For how many years has your organization conducted research in robotics?

☐ Less than 2 years
☐ 2 - 5 years
☐ 5 - 10 years
☐ Over 10 years

II. ROBOTICS RESEARCH AND EQUIPMENT

The questions in this section concern the specific type of robotics research being conducted and the type of robotics equipment being used in your organization.

7. Please indicate the areas of robot equipment research being conducted by your organization. Also estimate the annual research funds allocated to each area, if known:

Research Area	Annual Budget
☐ Sensing (vision or tactile)	$ ________
☐ Gripper design	________
☐ Robot control	________
☐ Programming	________
☐ Robot arm design	________
☐ Drive train	________
☐ Other ______________	________

8. Briefly describe the specific type of robotics research you are conducting in each of the following areas:

Sensing: ______________________________

Gripper design: ______________________________

Robot control: ______________________________

Programming: ______________________________

Robot arm design: ______________________________

Drive train: ______________________________

Other: ______________________________

9. At what stage of development is each major area of research?

	Basic Research	Initial Prototype	Final Prototype
Sensing	☐	☐	☐
Gripper design	☐	☐	☐
Robot control	☐	☐	☐
Programming	☐	☐	☐
Robot arm design	☐	☐	☐
Drive train	☐	☐	☐
Other: __________	☐	☐	☐

10. For each major area of robotics research, indicate the primary objective that you hope to accomplish by placing a number "1" in the space under the appropriate heading. Then indicate the second most important objective by placing a "2" under the appropriate heading.

	Expand Robot Application	Improve Robot Performance	Reduce Robot Cost	Improve Robot Safety	Other (______)
Sensing					
Gripper design					
Robot control					
Programming					
Robot arm design					
Drive train					
Other:__________					

11. Is your robotics research directed toward a particular manufacturing process? If so, indicate which one by checking the appropriate category below:

- ☐ No particular application
- ☐ Painting
- ☐ Welding
- ☐ Machining
- ☐ Foundry operations
- ☐ Machine loading
- ☐ Material handling
- ☐ Inspection
- ☐ Assembly
- ☐ Other:____________________

12. Indicate the manufacturer (brand) and model or type of each robot used in your research, along with the number of each used:

Manufacturer/Brand	Model No./Type	Number

13. Has your research required any type of modifications to be made to these robots?

☐ Yes   Please describe:______________________________

____

____

☐ No

14. How much do you expect your robotics research budget to increase over the next 3 years?

☐ No increase
☐ Up to 2 times the present level
☐ 2 - 5 times the present level
☐ More than 5 times the present level

III. FUTURE TRENDS - APPLICATIONS

Although an extensive number of potential applications exist for industrial robots, there are only about 5,000 robots currently in use in U.S. manufacturing operations. In this section, we would like your opinions about the future of industrial robotic applications.

15. (a) Which of the following best describes your feelings about the way the robot industry is likely to grow in the future?

☐ Explosive growth (similar to the computer industry)
☐ Periodic major increases as technological advances occur
☐ Steady but slow growth over a long period of time (similar to the numerical control industry)
☐ Only limited growth

(b) Please explain:____

____

____

____

____

16. By 1991 (ten years from now), how many robots do you expect will be in use in U.S. manufacturing plants relative to the estimated 5,000 now is use?

☐ About the same as today
☐ Up to 5 times as many
☐ 5 - 10 times as many
☐ More than 10 times as many

17. What percent of the work force in each of the following manufacturing applications do you expect will be replaced by robots five and ten years from now?

	1986	1991
Painting	_____	_____
Welding	_____	_____
Machining	_____	_____
Foundry operations	_____	_____
Machine loading	_____	_____
Material handling	_____	_____
Inspection	_____	_____
Assembly	_____	_____
Other:__________	_____	_____

18. Several factors may inhibit future growth in robot usage in these applications. For each of the following factors, indicate the extent to which you feel it is likely to have an impact on restricting future growth in robot equipment:

	Little/No Impact	Moderate Impact	Major Impact
Too much maintenance	☐	☐	☐
Installation difficulties	☐	☐	☐
Limited flexibility	☐	☐	☐
Inadequate cost savings	☐	☐	☐
Labor resistance	☐	☐	☐
Inadequate performance	☐	☐	☐
Education/training	☐	☐	☐
Equipment cost too high	☐	☐	☐
Other:________________	☐	☐	☐
Other:________________	☐	☐	☐

IV. FUTURE TRENDS - EQUIPMENT

In order for widespread usage of industrial robots to occur, the capabilities of robots must be able to meet the performance requirements of users. In this section, we would like your opinions about future requirements and trends in robotics equipment.

19. (a) In general, indicate the single most important area of robotics research likely to take place during the next five years by placing a number "1" in the appropriate space. Then indicate the second most important area of research by placing a number "2" in the appropriate box. Finally, place a "3" in the third most important area.

(a) General Research	Research Area	(b) Planned Research
________	Sensing	☐
________	Gripper design	☐
________	Robot control	☐
________	Programming	☐
________	Robot arm design	☐
________	Drive train	☐
________	Other:________________	☐
________	Other:________________	☐

19. (b) During the next five years, in which areas of equipment research does your organization plan to concentrate? (check all that apply in the list above)

20. In what areas do you feel that major technological breakthroughs are required in order for robot usage in industry to increase significantly in the future? Please indicate the nature of each breakthrough and the approximate year in which it is likely to occur.

Research Area	Required Breakthrough	Year of Development
☐ Sensing		
☐ Gripper design		
☐ Robot control		
☐ Programming		
☐ Robot arm design		
☐ Drive train		
☐ Other:		

21. Are there any other specific design improvements that you would recommend to robot manufacturers?

22. Any other comments?____

Thank you for participating in this survey. If you are conducting robotics research and wish to receive a free subscription to Manufacturing Technology Horizons along with a copy of the completed robotics report, include your name, organization, and address below.

NAME____

TITLE____

INSTITUTION/FIRM________________________________

ADDRESS______________________________________

CITY________________STATE_____________ZIP_______

TELEPHONE____________________________________

Do you have any published information describing your robotics research? If so, would you be willing to send us a copy of an abstract?

ROBOT MANUFACTURERS QUESTIONNAIRE

INDUSTRIAL ROBOT QUESTIONNAIRE

I. BACKGROUND AND SERVICES

In this section, we are interested in learning about your company, the types of services that you offer, and your thoughts about some of the factors that enter into a customer's decision in selecting a robot.

1. In what year did you first install an industrial robot?

____

2. Which of the following best describes the way your company entered the robot business?

☐ Company entered robot field as offshoot of other business
☐ Company was formed solely to produce robots

3. What is the primary geographic region in which your robots are sold?

☐ Region of the U.S.
☐ U.S.
☐ North America
☐ Worldwide

4. Do you offer complete turnkey system design?

☐ Yes
☐ No

5. Do you install robot systems for your customers?

☐ Yes
☐ No

6. Do you assist your customers in gripper fabrication?

☐ Yes
☐ No

7. Do you perform application engineering services for your customers?

☐ Yes
☐ No

8. Do you offer any type of analysis or audit of your customers' manfacturing operations?

☐ Feasibility analysis
☐ Cost/benefit analysis
☐ None
☐ Other:_______________

9. Do you offer a training program for robot purchasers?

☐ Maintenance
☐ Programming
☐ System operation
☐ No program offered

10. How long is the program?

____________Days

11. Where is the training conducted?

☐ Customer plant
☐ Manufacturer

12. Do you have a demonstration area set up where a prospective customer can see working models of your robots?

☐ Yes--with working models displayed
☐ Yes--with nonworking models
☐ No

13. What is an average delivery time for a typical robot system?

_____________Weeks

14. Can your robots be leased or rented?

☐ Leased
☐ Rented
☐ Neither

15. How long is your robot warranty?

______________________________ ______________________________

16. Do you offer a hardware service contract?

☐ Yes
☐ No

17. How many service center locations do you have in the U.S. (if any)?

____

18. What do you consider to be the most important reasons that your customers decide to use industrial robots? Place a number "1" by the reason you consider to be the most important. Then indicate the second most important reason with a number "2", and so on.

_____Elimination of hazardous/unpleasant work
_____Increase in productivity
_____Consistent product quality
_____Reduction in material costs
_____Reduction in direct labor costs
_____Desire to use new technologies
_____Other:____________________

19. How important are each of the following factors to your customers in deciding which type or manufacturer of robots to use?

	Not Important	Somewhat Important	Extremely Important
Flexibility/versatility	☐	☐	☐
Reliability of robot	☐	☐	☐
Cost	☐	☐	☐
Maintenance support	☐	☐	☐
Programming requirements	☐	☐	☐
Capabilities of robot	☐	☐	☐
Reputation of robot/supplier	☐	☐	☐

II. ROBOT EQUIPMENT AND SPECIFICATIONS

In the following tables, please tell us about the robot models offered by your company. In the spaces along the top of the tables, write the names of the basic robot models. Then answer the questions listed for each model. If more than 5 models are offered, please list most important models or reproduce appropriate pages.

Model number/name					
20. Date of first installation (year)					
21. Number installed to date worldwide					
22. Typical price (range) for one unit					
23. Maximum payload (lbs.)					
24. Accuracy (± inches)					
25. Repeatability (± inches)					
26. Number of degrees of freedom (axes)					
27. Type of positioning:					
Servo, point to point	☐	☐	☐	☐	☐
Servo, continuous	☐	☐	☐	☐	☐
Non-servo	☐	☐	☐	☐	☐
28. Coordinate system:					
Rectangular	☐	☐	☐	☐	☐
Cylindrical	☐	☐	☐	☐	☐
Spherical	☐	☐	☐	☐	☐
Jointed arm	☐	☐	☐	☐	☐
29. Standard grippers:					
None	☐	☐	☐	☐	☐
Vacuum	☐	☐	☐	☐	☐
Magnetic	☐	☐	☐	☐	☐
Parallel	☐	☐	☐	☐	☐
Angular	☐	☐	☐	☐	☐
Jointed fingers	☐	☐	☐	☐	☐
Other	☐	☐	☐	☐	☐

Model number/name					
30. Sensors offered:					
None	☐	☐	☐	☐	☐
Vision-photocell (diode)	☐	☐	☐	☐	☐
Vision-camera	☐	☐	☐	☐	☐
Vision-laser	☐	☐	☐	☐	☐
Tactile-limit switch	☐	☐	☐	☐	☐
Tactile-force feedback	☐	☐	☐	☐	☐
Tactile-proximity switch	☐	☐	☐	☐	☐
Tactile-current sensing	☐	☐	☐	☐	☐
Other	☐	☐	☐	☐	☐
31. Control system:					
Digital-microprocessor	☐	☐	☐	☐	☐
Digital-other	☐	☐	☐	☐	☐
Analog	☐	☐	☐	☐	☐
Discrete	☐	☐	☐	☐	☐
32. Programming method:					
Manual/teach	☐	☐	☐	☐	☐
On-line (CRT)	☐	☐	☐	☐	☐
Off-line	☐	☐	☐	☐	☐
33. Typical applications:					
Painting	☐	☐	☐	☐	☐
Welding	☐	☐	☐	☐	☐
Machining	☐	☐	☐	☐	☐
Foundry operations	☐	☐	☐	☐	☐
Die casting	☐	☐	☐	☐	☐
Machine loading	☐	☐	☐	☐	☐
Material handling	☐	☐	☐	☐	☐
Inspection	☐	☐	☐	☐	☐
Assembly	☐	☐	☐	☐	☐
Other	☐	☐	☐	☐	☐
34. Average installation time (days)					
35. Expected mean time before failure (hours)					
36. Average expected uptime (%)					
37. Typical expected payback period (years)					

III. FUTURE TRENDS

In order for widespread usage of industrial robots to occur, the capabilities of robots must be able to meet the performance requirements of users. In this section, we would like your opinions about future trends in robot equipment and applications.

38.(a) Which of the following best describes your feelings about the way the robot industry is likely to grow in the future?

☐ Explosive growth (similar to the computer industry)
☐ Periodic major increases as technological advances occur
☐ Steady but slow growth over a long period of time (similar to the numerical control industry)
☐ Only limited growth

(b) Please explain:____

____

____

____

39. By 1991 (ten years from now), how many robots do you expect will be in use in U.S. manufacturing plants relative to the estimated 5,000 now in use?

☐ About the same as today
☐ Up to 5 times as many
☐ 5 - 10 times as many
☐ More than 10 times as many

40. Five years from now, do you expect the average price of a typical industrial robot system to be higher or lower (in constant dollars) than the present price?

☐ Higher - By what percentage? ________%
☐ No Change
☐ Lower - By what percentage? ________%

41. What percent of the work force in each of the following manufacturing applications do you expect will be replaced by robots five and ten years from now?

	1986	1991
Painting	______	______
Welding	______	______
Machining	______	______
Foundry operations	______	______
Machine loading	______	______
Material handling	______	______
Inspection	______	______
Assembly	______	______
Other:____________	______	______

42. Several factors may inhibit future growth in robot usage in these applications. For each of the following factors, indicate the extent to which you feel it is likely to have an impact on restricting future growth in robot equipment:

	Little/No Impact	Moderate Impact	Major Impact
Too much maintenance	☐	☐	☐
Installation difficulties	☐	☐	☐
Limited flexibility	☐	☐	☐
Inadequate cost savings	☐	☐	☐
Labor resistance	☐	☐	☐
Inadequate performance	☐	☐	☐
Education/training	☐	☐	☐
Equipment cost too high	☐	☐	☐
Other:____________	☐	☐	☐
Other____________	☐	☐	☐

43. In what areas do you feel that major technological breakthroughs are required in order for robot usage in industry to increase significantly in the future? Please indicate the nature of each breakthrough and the approximate year in which it is likely to occur.

Research Area	Required Breakthrough	Year of Development
Sensing	______________________________	______
Gripper design	______________________________	______
Robot control	______________________________	______
Programming	______________________________	______
Robot arm design	______________________________	______
Drive train	______________________________	______
Other:__________	______________________________	______

44. Several robot users have indicated that certain improvements are needed in robot performance. In which of the following areas does your company plan to concentrate its development efforts during the next five years?

☐ Increased accuracy
☐ Increased repeatability
☐ Increased robot uptimes
☐ Higher number of degrees of freedom
☐ Greater speed
☐ Increased robot flexibility (more applications)
☐ Increased weight lifting capability
☐ Easier programming
☐ Increased gripper dexterity
☐ Greater robot safety
☐ Reduced equipment cost

45. In which of the following areas of robot capabilities are significant advances expected in your company's robots within the next five years?

- ☐ Sensing:
  - ☐ Visual
  - ☐ Tactile
  - ☐ Other: __________
- ☐ Gripper Design:
  - ☐ Multi-finger/flexible
  - ☐ Application specific grippers
  - ☐ General purpose grippers
  - ☐ Other: __________
- ☐ Robot Control:
  - ☐ Digital
  - ☐ Analog
  - ☐ Hierarchical
  - ☐ Other: __________
- ☐ Programming:
  - ☐ Teach
  - ☐ On-line (CRT)
  - ☐ Off-line
  - ☐ Higher level language
  - ☐ Other: __________
- ☐ Robot Arm Design:
  - ☐ More joints
  - ☐ Longer/shorter
  - ☐ Greater strength
  - ☐ Other: __________
- ☐ Other: __________

46. Any other comments? __________

Thank you for participating in this survey. If you wish to receive a free subscription to Manufacturing Technology Horizons along with a copy of the completed robotics report, include your name, address and organization below:

NAME __________
TITLE __________
COMPANY __________
ADDRESS __________
CITY __________ STATE __________ ZIP __________
TELEPHONE __________

ROBOT USERS QUESTIONNAIRE

INDUSTRIAL ROBOT QUESTIONNAIRE

I. BACKGROUND

Please answer the following questions about your plant and the manufacturing environment within which robots are employed.

1. How many direct labor production workers are in your plant?

☐ 0-100
☐ 101-200
☐ 201-300
☐ 301-400
☐ 401-500
☐ 500 and over

2. What types of products does your plant produce?

____

3. Is your manufacturing operation generally:

☐ Job Shop (Batch)
☐ High Volume

4. Do you use any of the following in your manufacturing operations?

	Not Used	Limited Use	Extensive Use
Numerical control equipment (NC)	☐	☐	☐
Computer aided design (CAD)	☐	☐	☐
Computer aided testing (CAT)	☐	☐	☐

5. Do you use industrial robots in your manufacturing operations?

☐ Yes
☐ No

(If not, proceed to question 52)

II. ROBOT EQUIPMENT AND APPLICATIONS

In this section, we are interested in the number and types of robots that you currently use, along with the manufacturing application for which they are used.

6. Listed below are a number of general manufacturing operations for which robots could be used. Please check those for which robots are currently employed in your plant. Then indicate the primary type of robot application in each area checked. (Example: welding--spot welding of automobile doors)

Manufacturing Operation	Robot Application(s)
Painting	______________________
	______________________
Welding	______________________
	______________________
Machining	______________________
	______________________
Foundry operations	______________________
	______________________
Machine loading	______________________
	______________________
Material handling	______________________
	______________________
Inspection	______________________
	______________________
Assembly	______________________
	______________________
Other:	______________________
	______________________
Other:	______________________
	______________________

7. For each of the primary manufacturing operations for which robots are used, indicate the number of units of each type of robot currently used in your plant.

ROBOT APPLICATIONS / MANUFACTURER AND MODEL	Painting	Welding	Machining	Foundry operations	Machine loading	Material handling	Inspection	Assembly	Other:	Other:
Unimation:										
1000	___	___	___	___	___	___	___	___	___	___
2000	___	___	___	___	___	___	___	___	___	___
4000	___	___	___	___	___	___	___	___	___	___
Puma 250	___	___	___	___	___	___	___	___	___	___
Puma 500/600	___	___	___	___	___	___	___	___	___	___
Apprentice	___	___	___	___	___	___	___	___	___	___
Cincinnati Milacron:										
T3	___	___	___	___	___	___	___	___	___	___
HT3	___	___	___	___	___	___	___	___	___	___
ASEA:										
IRb-6	___	___	___	___	___	___	___	___	___	___
IRb-60	___	___	___	___	___	___	___	___	___	___
PRAB:										
4200/5800	___	___	___	___	___	___	___	___	___	___
Versatran E	___	___	___	___	___	___	___	___	___	___
Versatran F	___	___	___	___	___	___	___	___	___	___
Auto-Place:										
10	___	___	___	___	___	___	___	___	___	___
50	___	___	___	___	___	___	___	___	___	___
DeVilbiss:										
TR-3000	___	___	___	___	___	___	___	___	___	___
Other:										
MOBOT: ___	___	___	___	___	___	___	___	___	___	___
Seiko: ___	___	___	___	___	___	___	___	___	___	___
___	___	___	___	___	___	___	___	___	___	___
Automatix: ___	___	___	___	___	___	___	___	___	___	___
Thermwood: ___	___	___	___	___	___	___	___	___	___	___
Other: ___	___	___	___	___	___	___	___	___	___	___

8. In what year did you first use robots in each manufacturing operation?

Manufacturing Operation	Year Robot First Used
☐ Painting	
☐ Welding	
☐ Machining	
☐ Foundry operations	
☐ Machine loading	
☐ Material handling	
☐ Inspection	
☐ Assembly	
☐ Other:	
☐ Other:	

9. Do any of the robots used in these manufacturing operations have sensing capabilities?

	Visual	Touch	Other
☐ Painting	☐	☐	☐
☐ Welding	☐	☐	☐
☐ Machining	☐	☐	☐
☐ Foundry operations	☐	☐	☐
☐ Machine loading	☐	☐	☐
☐ Material handling	☐	☐	☐
☐ Inspection	☐	☐	☐
☐ Assembly	☐	☐	☐
☐ Other:	☐	☐	☐
☐ Other:	☐	☐	☐

III. SELECTION PROCESS

In the following questions, we are interested in: (1) the process that you followed in deciding whether or not to use robots and (2) how you selected a particular type of robot.

10. For each of the manufacturing applications listed across the top of the following chart, indicate the single most important reason that you decided to use robots by placing a number "1" in the appropriate box. Then indicate the second most important reason by placing a number "2" in the appropriate box.

ROBOT APPLICATIONS / REASONS FOR USE	Painting	Welding	Machining	Foundry operations	Machine loading	Material handling	Inspection	Assembly	Other:	Other:
Hazardous/Unpleasant work	___	___	___	___	___	___	___	___	___	___
Increase in productivity	___	___	___	___	___	___	___	___	___	___
Consistent product quality	___	___	___	___	___	___	___	___	___	___
Reduction in material costs	___	___	___	___	___	___	___	___	___	___
Reduction in direct labor costs	___	___	___	___	___	___	___	___	___	___
Desire to use new technologies	___	___	___	___	___	___	___	___	___	___

11. Who provided the initial motivation to begin looking at possible robot applications in your plant?

☐ Manufacturing/production engineering
☐ Top management
☐ Plant manager
☐ Robot manufacturer
☐ Other: ______________________

12. Before purchasing robots, did your company conduct an audit of manufacturing operations to determine the feasibility of using robots?

☐ Formal audit was conducted
☐ Informal audit was conducted
☐ No audit was conducted

13. Did your company conduct a cost/economic study of robots vs. manual labor?

☐ Detailed study was conducted
☐ Brief overview study was conducted
☐ No study was conducted

14. Did your company first purchase a robot for use in laboratory testing, or were robots immediately installed on the production line?

☐ First used in laboratory
☐ Used immediately on production line

15. Indicate the single most important source of information in making the robot selection decision by placing a number "1" in the appropriate space. Then indicate the second most important source by placing a number "2" in the appropriate space.

________ Manufacturer
________ Independent consultant
________ Other robot users
________ Conferences, trade shows
________ Journals, literature
________ Research organizations

16. Were you able to see a model of this robot in operation before purchasing one? If so, where?

- ☐ Demonstration at the robot manufacturing facility
- ☐ Demonstration at your plant
- ☐ Visit to another user's plant
- ☐ Manufacturer films
- ☐ Trade show/convention

17. How important were each of the following factors to your company in deciding which type or manufacturer or robots to use?

	Not Important	Somewhat Important	Extremely Important
Flexibility/versatility	☐	☐	☐
Reliability of robot	☐	☐	☐
Cost	☐	☐	☐
Maintenance support	☐	☐	☐
Programming requirements	☐	☐	☐
Capabilities of robot	☐	☐	☐
Reputation of robot/ supplier	☐	☐	☐

IV. INSTALLATION AND ECONOMICS OF USE

Many robot manufacturers claim that the initial cost of a robot will be recovered within one or two years. We would like to know if your experience compares with this. Please select an example of a robot used in a particular application for which you have a feel for the economics of the application. This robot should be a representative sample of the types of robots that you are currently using.

18. Please indicate the robot manufacturer and model or type:__________

____

19. Year of purchase: ______________________________

20. For what application is it used? ______________________________

____

21. How is it programmed?

☐ Manual/teach
☐ On-line (CRT)
☐ Off-line (Another computer)

22. Who installed the system?

☐ In-house staff
☐ Manufacturer
☐ Consultant

23. What was the total time required for installation? __________ days.

24. Which of the following were required during installation (check all that apply)?

☐ Retooling
☐ New/special tooling
☐ Wiring/electrical
☐ Air/hydraulic lines
☐ Moving equipment
☐ Rearranging work area
☐ Other: ____________________________

25. How many days of testing were conducted before production operations began? ____________ days.

26. From the time this robot was put into production, what was the length of time required to reach a 100% production level?

________________ days

27. What problems, if any, did you encounter during the process of installing the robot?

____

____

____

28. Were employees retrained to use the robot?

☐ Yes
☐ No (proceed to question 33)

16. Were you able to see a model of this robot in operation before purchasing one? If so, where?

- ☐ Demonstration at the robot manufacturing facility
- ☐ Demonstration at your plant
- ☐ Visit to another user's plant
- ☐ Manufacturer films
- ☐ Trade show/convention

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Cost	☐	☐	☐
Maintenance support	☐	☐	☐
Programming requirements	☐	☐	☐
Capabilities of robot	☐	☐	☐
Reputation of robot/ supplier	☐	☐	☐

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18. Please indicate the robot manufacturer and model or type: ____________

____

19. Year of purchase: ______________________

20. For what application is it used? ______________________

____

29. Who conducted the training program?

☐ In-house staff
☐ Manufacturer
☐ Consultant

30. Who participated in the training program?

☐ Manufacturing/production engineers
☐ Maintenance personnel
☐ Plant management
☐ Direct labor personnel

31. For how many days was the training program conducted?

_____________ days

32. Did the training program adequately meet your needs?

☐ Yes
☐ No - Why not? ____________________
____
____

33. How many shifts per day are there for this application?

____

34. Was there a net change in the number of direct labor personnel required for this application?

☐ Yes - Increase of ________ personnel
- Decrease of ________ personnel

☐ No

35. How many indirect labor personnel (e.g. maintenance) were added?

____

36. What percent of the time is this robot out of service for maintenance or repairs?

______________%

37. How long does it take to change/set up a job?

______________ hours

38. What was the approximate purchase cost of this robot system, including all accessories, but not including the cost of installation?

$______________

39. What was the cost of all accessories (gripper, base, etc.) as a percent of the system purchase cost?

______________ % (or $______________)

40. What was the total cost to install this robot as a percent of the system cost?

______________ % (or $______________)

41. What is the annual maintenance cost for this robot as a percent of the system cost?

______________ % (or $______________)

42. What is the total of all other recurring annual costs for this robot as a percent of the system cost (e.g., retooling, direct power consumption, etc.)?

______________ % (or $______________)

43. What is the net reduction in annual direct labor cost for this robot as a percent of the system cost?

______________ % (or $______________)

44. What is the overall cost reduction, if any, resulting from use of this robot as a percent of the system cost?

______________ % (or $______________)

45. What was (or will be) the approximate payback period for this robot?

______________ years

V. EXPERIENCE

The following questions refer to your experiences in using robots in normal production operations. We are interested in problems as well as positive experiences that you have encountered.

46. How are robots in your plant generally viewed by direct labor employees?

☐ As a means to eliminate unpleasant work
☐ As a means to upgrade employee's skills
☐ No opinion
☐ As a threat to job security

47. What does top management perceive as being the most important benefit of using robots?

☐ Cost reduction
☐ Enhanced corporate image
☐ Improved worker morale
☐ Increased product quality
☐ Other: ______________________________
____

48. Which of the following best describes your overall evaluation of the performance of robots in your plant?

☐ Greatly exceeds expectations
☐ Exceeds expectations
☐ Meets expectations
☐ Is below expectations
☐ Is greatly below expectations

49. What problems or disappointments, if any, have you encountered in using robots? (Check all that apply for each application.)

	Painting	Welding	Machining	Foundry operations	Machine loading	Material handling	Inspection	Assembly	Other:	Other:
Not flexible enough										
Too slow										
Too much downtime/ maintenance										
Poor positioning accuracy										
Takes up too much space										
Inadequate cost savings										
Too difficult to use										
Primitive technology										
Installation time too long										
Labor resistance to robots										

50. Any other problems or disappointments? Any unexpected positive experiences?

51. Now that you've had experience with robots, do you have any suggestions or warnings for prospective robot purchasers?

____

____

____

____

VI. FUTURE

The following questions refer to plans for robot usage in your plant in the future. Also, there are several questions covering your opinions about and expectations for the future of robotics.

52. Do you plan to purchase more robots in the next two years?

☐ Yes

☐ No

53. Is there any application in your plant for which you believe robots could be used but are not now being used? ____________________

____

54. Why are currently available robots not being used in this area at present? ______________________________

____

55. Indicate the areas in which you feel major improvements are needed in robot capabilities for each of the following applications.

	Painting	Welding	Machining	Foundry operations	Machine loading	Material handling	Inspection	Assembly	Other:	Other:
Vision sensing										
Location/shape sensing										
Force sensing										
Weight of object lifted										
Number of degrees of freedom										
Ability to teach										
Flexibility										
Reliability										
Speed										
Programming										
Gripper dexterity										
Other:										

56. What percent of each of the following manufacturing operations in your plant do you expect to be performed by robots in the future?

	Current	1985	1990
Painting			
Welding			
Machining			
Foundry operations			
Machine loading			
Material handling			
Inspection			
Assembly			
Other:			
Other:			

57. Other comments? Problems? Needs? Ideas? Predictions? Experiences? Etc.? ______________________________

Thank you for participating in this survey. If you are a robot user and wish to receive a free subscription to Manufacturing Technology Horizons along with a copy of the completed robotics report, include your name, company, and address below.

NAME ______________________________

TITLE ______________________________

COMPANY ______________________________

ADDRESS ______________________________

CITY ____________________ STATE __________ ZIP ______

TELEPHONE ______________________________

APPENDIX D

SAMPLE INTRODUCTORY LETTER

FOR ROBOT REPORT QUESTIONNAIRES

TECH TRAN CORPORATION
1062 ALTON COURT, NAPERVILLE, ILLINOIS 60540 (312)369-9232

Tech Tran Corporation is currently preparing a major report on industrial robots. This report will address the state-of-the-art in robot equipment, manufacturing applications and their pros and cons, practical guidelines for equipment selection and implementation, and a forecast of future developments and usage.

This report on industrial robots will be made available on a limited basis to new subscribers of Manufacturing Technology Horizons, a bi-monthly digest on new manufacturing technology developments. The enclosed press release and brochure provide additional information on the publication.

Although much of the material for the robot report has already been gathered, we want to include as much information as possible from actual robot users or potential users. All too often reports of this type focus only on technology and the sometimes overly optimistic promotional statements made by equipment manufacturers. We hope to produce a real-world, unbiased overview of industrial robots by tempering the material we have with information on actual shop floor experience. To our knowledge, this will be the first report to summarize the experiences of many robot users. This information will also play a major role in determining whether or not the field of robotics is likely to achieve the explosive growth predicted by many experts.

To this end, we are conducting a survey of companies such as yours which are either users of industrial robots or are actively considering their use. We would appreciate if you would take about one hour of your time to complete the enclosed questionnaire.

Let me assure you that your response will be held in the strictest confidence. The information you provide will be consolidated with that received from other respondents and only combined summaries will be included in the report. Your input will remain anonymous and the data will be presented in such a manner that it would be impossible to identify individual responses.

We realize that completing this questionnaire will take time, and we would like to repay you for your efforts. Therefore, if you complete the enclosed questionnaire and return it in the postage paid envelope by October 31, 1981, we will send you a complimentary copy of the completed report and a free one-year subscription to Manufacturing Technology Horizons.

If you won't have time to fill out the questionnaire in the next few weeks, or you believe someone else in your organization is more qualified to answer the questions, please feel free to route the questionnaire to the appropriate individual in your company.

Thank you in advance for your participation.

Sincerely,

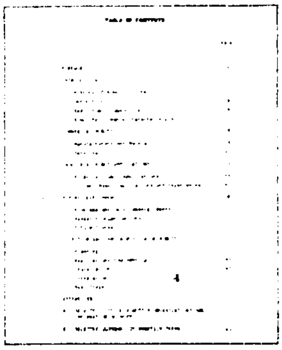
Ronald J. Sanderson
Senior Project Manager

RJS:ck

Encs.

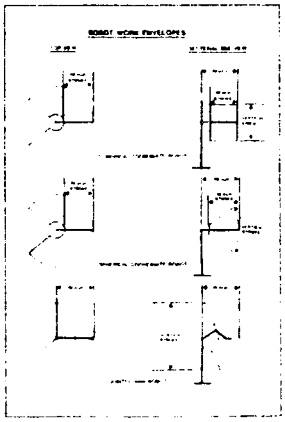
APPENDIX E

ROBOTIC PROMOTIONAL LITERATURE



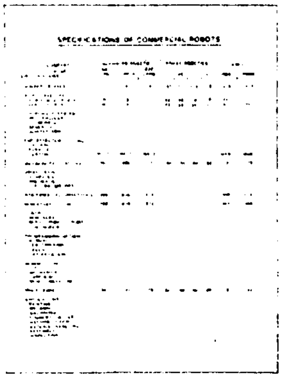
CONTENTS

The report provides a single source for information on the fundamentals of robot technology, commercially available equipment, suitable applications, a forecast of future developments and trends, and a thorough discussion of how to select and implement robots.



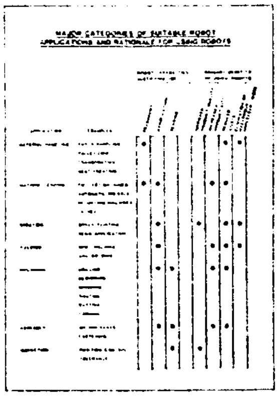
BASIC TECHNOLOGY

In non-technical language, the report describes what robots are and how they work. Basic definitions, major components, categories of robots, and principals of operation are covered.



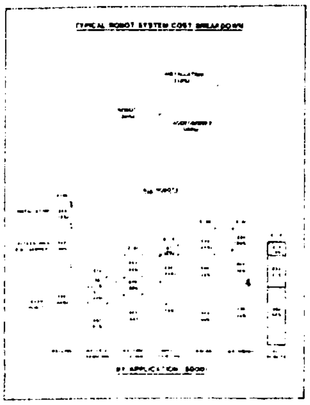
EQUIPMENT GUIDE

An up-to-date directory of more than 70 robots currently available in the U.S. is contained in the report, including manufacturers, models, equipment specifications, performance characteristics, and appropriate applications.



APPLICATIONS

Industrial robots are being used in a wide variety of manufacturing operations, ranging from spray painting to assembly. The report discusses each application area and examines advantages and disadvantages of their use.

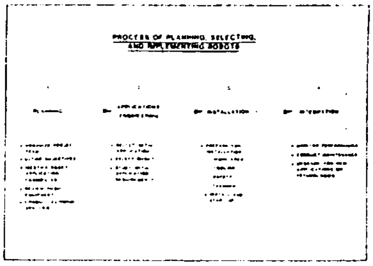


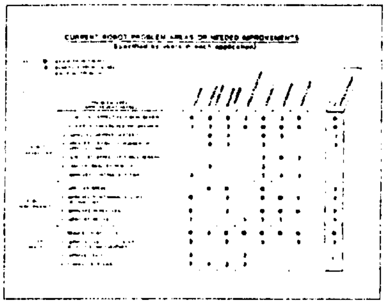
ECONOMICS OF USE

Actual payback periods for companies which have used robots are reviewed, along with an analysis of the costs and savings that can be expected. A practical approach for evaluating the economics of robot applications is also discussed.

SELECTION AND IMPLEMENTATION

A four-step procedure for robot selection and implementation is described, including evaluation of applications, equipment selection and justification, applications engineering, installation and start-up, and integration into factory operations



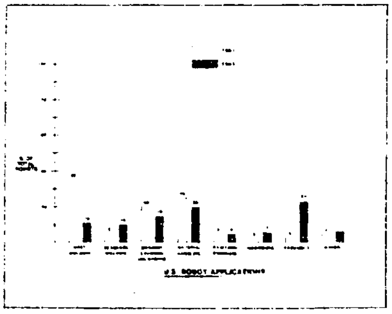


USERS EXPERIENCES

Based on survey of companies using robots in a variety of manufacturing applications, real-world experiences in selection, installation, and use are examined.

FUTURE TRENDS

High-growth application areas and anticipated technical developments that will affect future robot use are explored, and a forecast of robot installations through 1991 is presented.



This special report — prepared by Tech Tran's technical staff — will bring you to the leading edge of industrial robot technology. It is:

COMPREHENSIVE — Covers the entire spectrum of industrial robot types, manufacturers, applications and developments taking place.

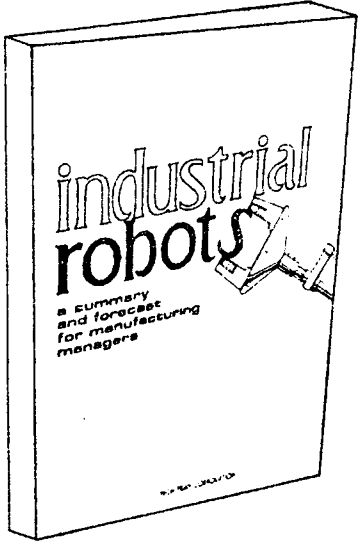
UNBIASED — Looks at both benefits and potential problems in using industrial robots and presents results of first major user survey in this field.

PRACTICAL — Tells you how to identify potential robot applications, select appropriate models, and plan and execute shop floor implementation.

READABLE — The subject matter is presented in concise, understandable terms and emphasizes issues affecting widespread use of this new technology.

CURRENT — Prepared using the latest available data and additional information developed by Tech Tran.

1982



ORDER YOUR COPY TODAY

Yes, please send me a copy of "Industrial Robots — A Summary and Forecast for Manufacturing Managers." ($50 in the U.S., Canada and Mexico; $65 elsewhere.)

☐ Payment enclosed

☐ Bill Me (Signature)

NAME TITLE

COMPANY

ADDRESS

CITY STATE ZIP

COUNTRY PHONE ( )

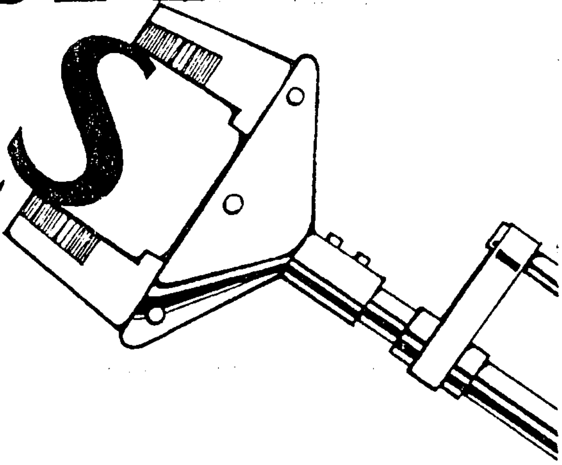
Please mail to: Tech Tran Corporation, 134 N. Washington St., Naperville, Illinois 60540. (312) 369-9232.

APPENDIX F

ROBOT REPORT

industrial robots

a summary and forecast for manufacturing managers



TECH TRAN CORPORATION

INDUSTRIAL ROBOTS: A SUMMARY AND FORECAST FOR MANUFACTURING MANAGERS

RONALD J. SANDERSON
JOHN A. CAMPBELL
JOHN D. MEYER

PUBLISHED BY:
TECH TRAN CORPORATION
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NAPERVILLE, ILLINOIS 60540 USA
(312/369-9232)

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FOREWORD

Many observers feel that industrial robot technology represents the final major technological breakthrough required to achieve the longstanding dream of manufacturing executives--the automated factory.

Since the development of industrial robots in the early 1960's, however, only a small portion of this goal has been achieved. Through the 1960's and early 1970's, industrial robot applications were limited to a few simple transfer operations. Even today, as robots have become increasingly sophisticated, there are only a few thousand in use in U.S. manufacturing plants.

Until recently, there were two basic factors which limited industrial robot growth. First, with increasing productivity and reasonable labor rates in the 1960's, the need for robots was not as great as today. Second, robot capabilities were relatively primitive until the early to mid-1970's.

Today, however, the situation has changed dramatically. With a rapid escalation of labor costs, a decreasing rate of productivity growth, and an increasing concern over safety and environmental factors in jobs, the need for robots has become firmly established. At the same time, there have been major advances in robot capabilities, including improvements in flexibility, control and sensing. The result has been a recent surge in robot usage in industrial applications.

Although robot capabilities have improved substantially in recent years, the level of understanding of how to apply them has not kept pace. In order for currently available industrial robots to achieve their full potential, users need to understand what robots are, where they can be used, and how to justify and select them. This report has present an overview of the field of industrial robots, to help the potential user decide whether or not robots make sense in a particular manufacturing operation, to show the potential user how to select and use robots, and to take a look at some of the more important developments likely to take place in the robotics field during the next several years.

To accomplish these goals, all important literature published to date on industrial robot technology and applications was reviewed. In addition, surveys were conducted of robot manufacturers, research organizations, and companies that have used robots in their manufacturing operations. Many of the observations in this report are based upon the experiences of these robot users.

This report was prepared for manufacturing managers, engineers, supervisors, technical specialists, top management, and anyone else who needs to better understand what this fast paced field is all about. It is not intended to be a technical manual. Rather, it is written to provide an overview of the field from a practical, business oriented point of view.

"Industrial Robots - A Summary and Forecast for Manufacturing Managers" begins with an introduction to industrial robots in Chapter 1. This includes the history and evolution of robots, definitions and ways of classifying robots, the basic technology of robots, and the capabilities currently available in each type of robot.

Chapter 2 reviews the characteristics of commercially available robots being used in industrial applications. Profiles of robot suppliers are also presented, including company backgrounds and detailed specifications on the major robot models offered by each company.

In Chapter 3, specific industrial applications of robots are discussed, including the types of robots being used, criteria that must be satisfied for use in each application, and the economics of using robots versus alternative forms of automation.

Chapter 4 presents a discussion of the major developments in robot capabilities and applications likely to occur in the future. This includes a summary of current problems/needs in robot design and an analysis of the type of research being performed to resolve these problems.

Chapter 5 is a "how to" guide to the planning, selection, and implementation of industrial robots. In this chapter are a number of techniques to help the potential user complete the process with a minimum number of problems.

Two appendices provide a list of selected robotics information sources, organizations, and a glossary of commonly used terms.

We wish to express our gratitude to the many knowledgeable individuals who participated in the surveys that provided some of the background information for this report. We also wish to thank the manufacturers and research organizations for bringing robotics technology to the advanced state at which we find it today.

INTRODUCTION

During the 1960's and 1970's, the manufacturing environment in the U.S. was affected by such economic problems as rapidly increasing inflation, high energy costs, increased government regulations, and increasing worker resistance to performing repetitive or hazardous jobs. One major effect of these factors was that companies increasingly invested in capital equipment which had short payback periods. Long term projects, such as major capital equipment investments or facility modernization, were postponed. As a result, the average age of facilities and equipment in the U.S. has been increasing relative to that of other industrialized nations. At the present time, two-thirds of all U.S. machine tools used in industry are over ten years old, and one-third are over twenty years old.

Since productivity growth is directly related to both the rate of new capital investment and the rate of development of new technological advances, it is not surprising that the average annual productivity growth for the U.S. was the lowest of all major industrialized nations during the 1960's and 1970's. From 1973 through 1979, the average annual growth in productivity in the U.S. was less than 1% per year, which was a major decrease from the 3% per year average growth during the 1960's. In 1979, productivity growth actually declined for the first time in history, with an annual decrease of 0.9% recorded.

At the same time productivity growth has been slowing, direct labor costs have increased dramatically. Typical hourly rates for manufacturing direct labor personnel have increased from $4-5 per hour in the 1960's to current rates of $16-17 per hour. Part of this increase is due to inflation, but some of it is also due to an increasing reluctance on the part of many direct labor personnel to perform jobs that are considered monotonous, fatiguing, hazardous, or unpleasant.

Two related trends have, therefore, had a negative impact on the manufacturing environment in the U.S. during the 1970's. Productivity growth has declined while direct labor costs have increased sharply. Manufacturing managers have increasingly considered the use of new manufacturing technology as a means of resolving both of these problems. Such technologies as numerical control (NC) systems, computer aided design (CAD), computer aided manufacturing (CAM), and robotics have all been used in various types of manufacturing applications in recent years.

The limitation to most forms of fixed, or dedicated, automation was that they could only be used in certain high volume manufacturing operations requiring only the simplest types of motions. Robots, on the other hand, could be used in operations where a certain degree of manipulation was required. In other words, a much larger number of tasks formerly requiring manual labor could now be automated. This unique capability to perform tasks requiring the manipulation of objects, combined with the need to reduce direct labor costs and the need to increase productivity, has resulted in an enormous interest in robots on the part of manufacturing managers.

HISTORY OF ROBOTS IN THE U.S.

The first industrial robot developed in the U.S. was delivered and installed in a General Motors automobile plant in 1961. This robot is now "retired" and is located at the Smithsonian Institute, Washington, D.C. It was designed and manufactured by Unimation, Inc., the pioneering firm in the robotics field and presently the world's largest robot supplier. The earliest applications of robots were in foundry operations, such as the loading and unloading of die cast machines. Another early application was the use of robots for spot welding (for example, automobile bodies).

From the start, predictions of growth for the robot industry were similar to those made for the computer industry. However, the growth pattern of the robot industry has not followed that of the computer industry, for several reasons. First, the economic environment during the 1960's was not conducive for rapid growth. The average cost of an early robot was about $25,000, the robot had an expected life of about 8 years, and it cost approximately $4/hour to operate. Typical labor costs were considerably less than the operating cost of robots at that time. Secondly, the technology was new, unproven, and risky, and considerable capital investment was required. And third, the control and feedback technology which was available at that time limited robotics applications to only a few simple jobs.

As a result, by 1970, ten years after their introduction, only about 200 robots were in use throughout the U.S. These robots were used primarily in jobs which humans either did not or could not perform. The jobs were hazardous, hot, boring, or required lifting heavy loads for long periods of time. During the 1970's, however, the economic environment in the U.S. changed considerably. The productivity growth of manufacturing organizations declined while labor rates increased. These trends occurred at the same time that control, flexibility, and manipulative capabilities of robots were being improved. By the mid-1970's, usage of robots in manufacturing operations began to increase significantly, as manufacturing managers perceived the potential value of these unique machines.

Although there have been significant increases in both labor and material costs in the robot industry, the average price of robots has only increased to about $40,000-50,000, and the annual operating cost has increased to around $5.00 per hour. The reason that robot costs have not increased excessively is because approximately 75% of the cost of the earlier robots was in electronic hardware and 25% in mechanical hardware. Although the electronic systems used in robots have become more sophisticated over the years, the actual cost of this hardware has increased very little, so that now the mechanical hardware shares the larger portion of the cost. With robots becoming more sophisticated while at the same time becoming less costly relative to human labor, the advantages of robots became readily apparent during the mid-1970's.

As seen in Exhibit 1, the average hourly direct labor cost in the automotive industry has been more than twice the average hourly cost of an industrial robot since the mid-1970's. This is the time when the industry began to grow significantly. During the past two years, in particular, the robot industry has grown at an annual rate of approximately 50% per year, and it is predicted to continue growing at a comparable rate in the near future.

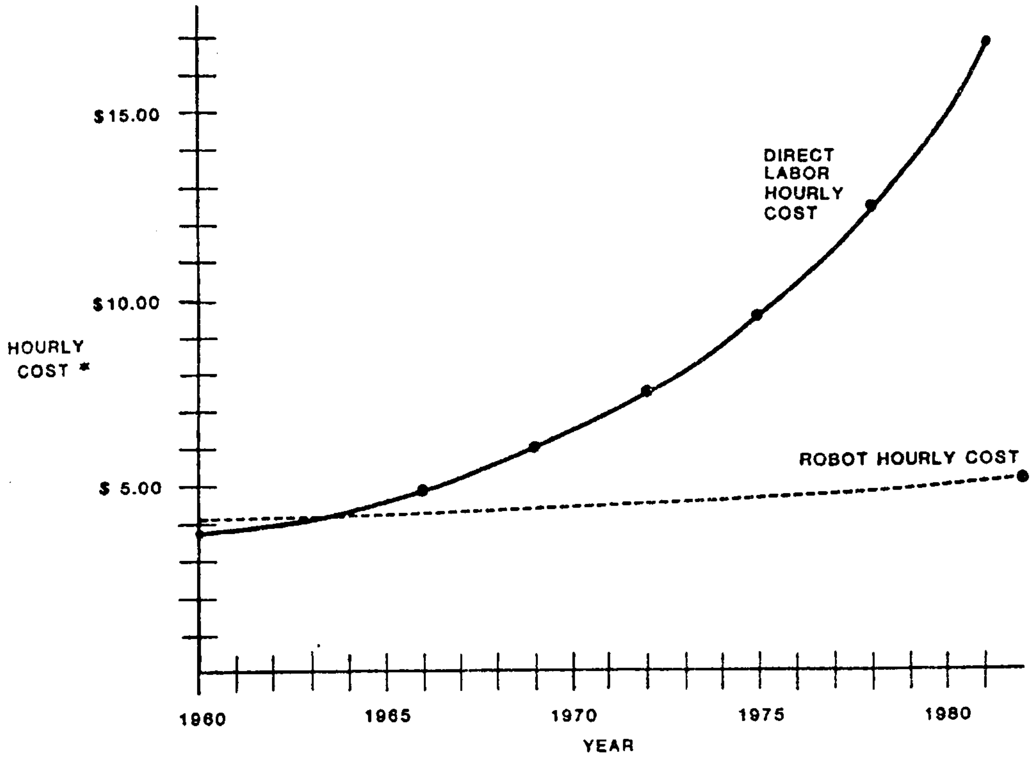
As of the end of 1981, there are approximately 4,500 robots in use in the U.S., with more than one-third of them used in one application, spot welding. More than two-thirds of all robots in use were supplied by the two leading manufacturers of robots, Unimation and Cincinnati Milacron.

DEFINITION

There is some confusion over the exact definition of an industrial robot. In order to understand what a robot is, it is best to start by reviewing the various categories of manufacturing automation. Automation ranges in degree from simply the use of powered or nonpowered tools to the complete control of a task by a computer-aided manufacturing system, involving high storage memories, sensory devices, and periodic changes in programming. Between these

EXHIBIT 1

HOURLY LABOR COST OF AUTOMOTIVE WORKER VS. INDUSTRIAL ROBOT IN THE U.S., 1960-1981



* DIRECT LABOR COST INCLUDES FRINGE BENEFITS: ROBOT COST INCLUDES SUPPORT

extremes fall the categories of "hard automation" and "flexible automation".

In hard automation, a task is performed by a tool which has been set up using mechanical limits and adjustments so that no human control is required during operations. Hard automation is typically dedicated to one application throughout the life of the tool. The primary disadvantage of hard automation is the difficulty of justifying the investment in dedicated equipment for a batch manufacturing operation, in which changeovers may be required. An additional drawback is the need for human assistance in loading and unloading the tool.

The alternative to hard automation until recently was to increase the direct labor content of a manufacturing task. Flexible automation was developed as a means of increasing the range of tasks that can be performed and also to improve the changeover capability of manufacturing tools. In flexible automation, a tool is pre-programmed by a human as in hard automation. In this case, however, the workpiece can be manipulated so that a greater number of tasks can be performed in each cycle, such as machine loading and unloading or part transfer. In addition, a changeover to another job can typically be accomplished by reprogramming rather than by reworking or replacing the equipment. Machinery can, therefore, be more productively used throughout its useful life.

Industrial robots can be classified as a type of flexible automation. What specifically is a robot? The Robot Institute of America (RIA) defines a robot as a "reprogrammable multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motion for the performance of a variety of tasks." Joseph Engelberger, who is the president of Unimation, the pioneering firm in the U.S. robotics field, defines an industrial robot as a "programmable manipulator with a number of articulations." The Japanese Industrial Robot Association has defined four levels of industrial robots:

- Manual manipulators that perform sequences of tasks which are fixed or present.
- Playbacks that repeat fixed instructions.
- Numerically controlled robots that carry out tasks through numerically loaded information.
- Intelligent robots that perform through their own recognition capabilities.

The Robot Institute of America does not include manual manipulators in its definition of industrial robots, and so estimates of the number of robots in use in each country are not directly comparable. Estimates of robots in Japan range to as high as 50,000. However, the number of machines in use in Japan that would be considered robots acording to the RIA definition is probably in the range of 10,000--15,000 as of the end of 1981. In the U.S., there are some 4,000-5,000 industrial robots in use.

The RIA definition of industrial robots is the best one to be presented to date. The first three words in the definition are essential to understandng the basic concept of a robot:

- "Reprogrammable" - An industrial robot is controlled by a programmable controller with memory, such as a microprocessor. The controller is programmed to command the robot arm and gripper to repeat a specified series of movements, such as moving a workpiece through a drilling operation. If the robot is to be used in a different operation, an entirely new sequence of movements can be created by reprogramming the controller.

- "Multifunctional" - An industrial robot is much more flexible than hard automation in that it can perform a wide variety of tasks. During a single cycle of movement, for example, a robot can load a machine, unload the workpiece, transport it to another machining operation, deburr the part, and load it on a conveyor belt. It is therefore a general purpose device rather than a dedicated machine.

- "Manipulator" - An industrial robot differs from other forms of automation in its ability to move an object through space while at the same time reorienting its position. It is this ability to manipulate objects that leads to the inevitable comparisons between robots and human arms and hands. This is also the capability which allows robots to perform many tasks that previously could only be performed by human workers.

Robots can thus be thought of as machines that fill the gap between the specialized capabilities normally associated with hard automation and the extreme flexibility of human labor. Basically, a robot is a device with a single arm for manipulating tools or parts through a programmed sequence of motions through space. What differentiates a robot from other types of automation is its ability to perform a sequence of several different, repetitive motions without the need for human involvement. Because of this unique capability to perform several different tasks, robots are used in a variety of industrial applications where the task can be performed in a more safe and effective manner by robots than by human workers.

BASIC COMPONENTS

Although industrial robots are available in a wide variety of configurations, all robots consist of three basic elements: (1) a manipulator, (2) a controller, and (3) a power supply. The manipulator (and its support stand) is the basic mechanical element of the robot, and is responsible for performing the work. The controller is the robot's brain, and is responsible for directing the movement of the manipulator. The power supply is the energy source for the manipulator.

Manipulator

The most fundamental objective of an industrial robot is to move an object through three-dimensional space. This motion is mechanically accomplished by the manipulator. The manipulator consists of a mechanical "arm" and a "wrist", both of which are mounted on a support stand. A mounting surface is provided on the end of the wrist for attaching the tool (called an "end effector") with which the robot performs its jobs. Typically, the end effector is in the form of a gripper device for grasping and manipulating a part.

Mechanical Configurations

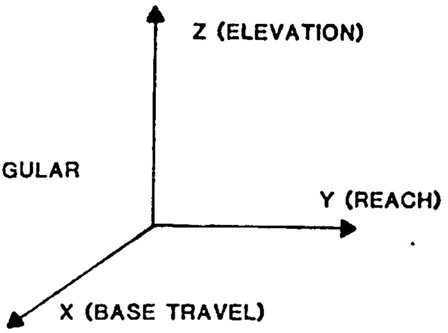
There are several ways in which a manipulator can be constructed in order to move a part through space. As in the human arm, motion is achieved through a series of mechanical linkages and joints. The basic configuration of the mechanical arm is best described in terms of its coordinate system. There are currently four different coordinate systems being used to move a part from point "A" to point "B". The simplest is the rectangular, or cartesian coordinate system, as illustrated in Exhibit 2. In this system, all motion is translational, i.e., straight along one of three perpendicular axes. This type of motion is the easiest to control, and is often used in the "pick and place" type of robot, which is used for such applications as transporting parts from one point to another.

EXHIBIT 2
PAGE 1 OF 2

ROBOT CONFIGURATIONS: RECTANGULAR

COORDINATE SYSTEM

RECTANGULAR



TYPICAL ROBOT DESIGN

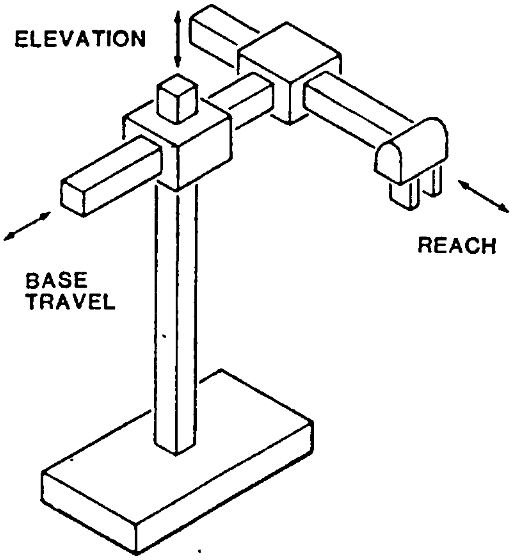
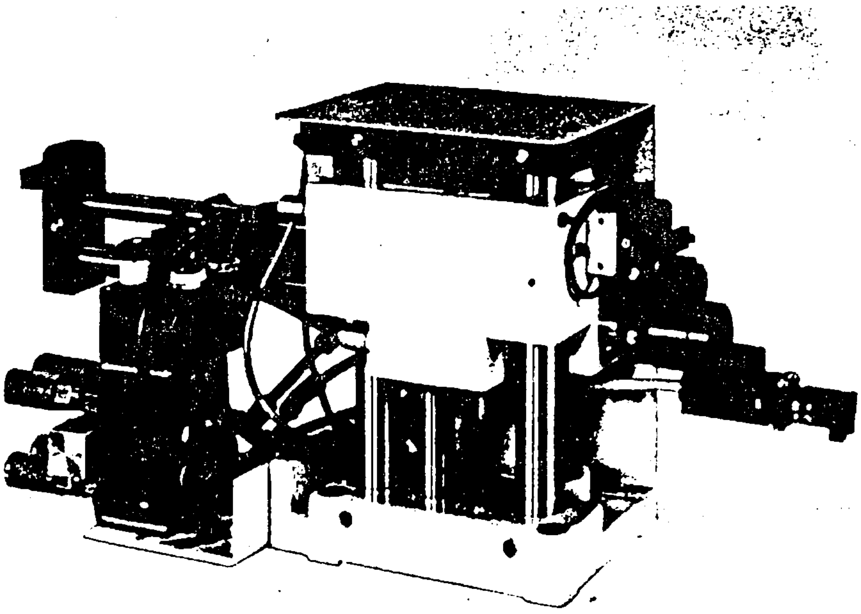


EXHIBIT 2
PAGE 2 OF 2

ROBOT CONFIGURATIONS: RECTANGULAR



EXAMPLE OF A RECTANGULAR COORINATE ROBOT: SEIKO 100 TRANSFER ROBOT (PHOTO COURTESY OF SEIKO INSTRUMENTS INC.)

Robot arm configurations based upon rotational motion about several axes, although being more difficult to control, are preferred in most currently available robots because of the simpler robot design requirements as well as the greater range within which such robots can work. Three rotational systems are in use today: cylindrical, spherical, and jointed-arm spherical (see Exhibits 3, 4, and 5).

The importance of each of these systems to a potential user is determined by the "work envelope" within which the robot end effector is capable of working. A robot work envelope is analogous to a human work envelope defined by industrial engineers. Robot manufacturers will normally include drawings of work envelopes for each robot model, along with dimensions. It is important to understand how the manufacturer defines the work envelope. Typically, the work envelope includes the region of space which can be reached by a particular point on the wrist of the manipulator, not the tip of the end effector. This is because the end effector is generally a custom designed item provided by the user, and so its dimensions cannot be predicted by the manufacturer. In planning for the placement of equipment near the robot and for the safety of workers, the robot purchaser must take into account the additional reach that will be provided by the end effector when attached to the wrist of the manipulator.

Typical work envelope shapes for each of the basic rotational coordinate systems are shown in Exhibit 6. A cylindrical coordinate robot has a work envelope in the shape of a portion of a cylinder. It consists of a horizontal arm attached to a vertical column, which is mounted on a rotating base. Motion is a combination of translational and rotational movements. The horizontal arm moves radially in and out while moving up and down on the column. Both pieces rotate about the base.

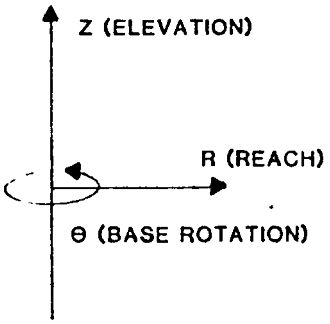
The spherical coordinate robot is similar to a tank turret. A boom arm extends and retracts, pivots in a vertical plane, and rotates

EXHIBIT 3
PAGE 1 OF 2

ROBOT CONFIGURATIONS: CYLINDRICAL

COORDINATE SYSTEM

CYLINDRICAL



TYPICAL ROBOT DESIGN

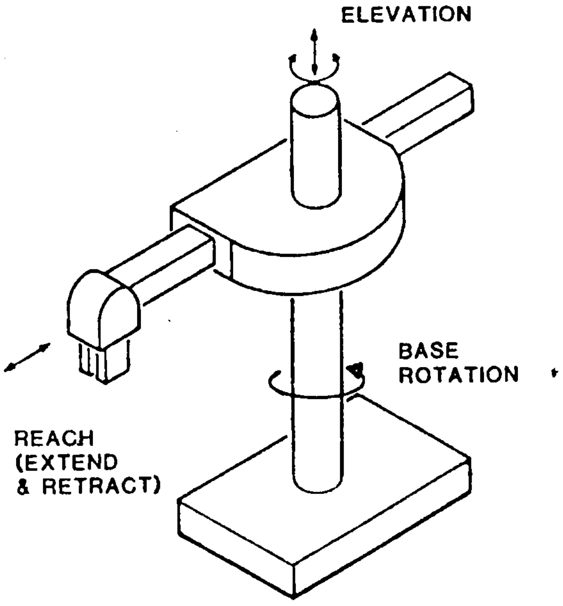
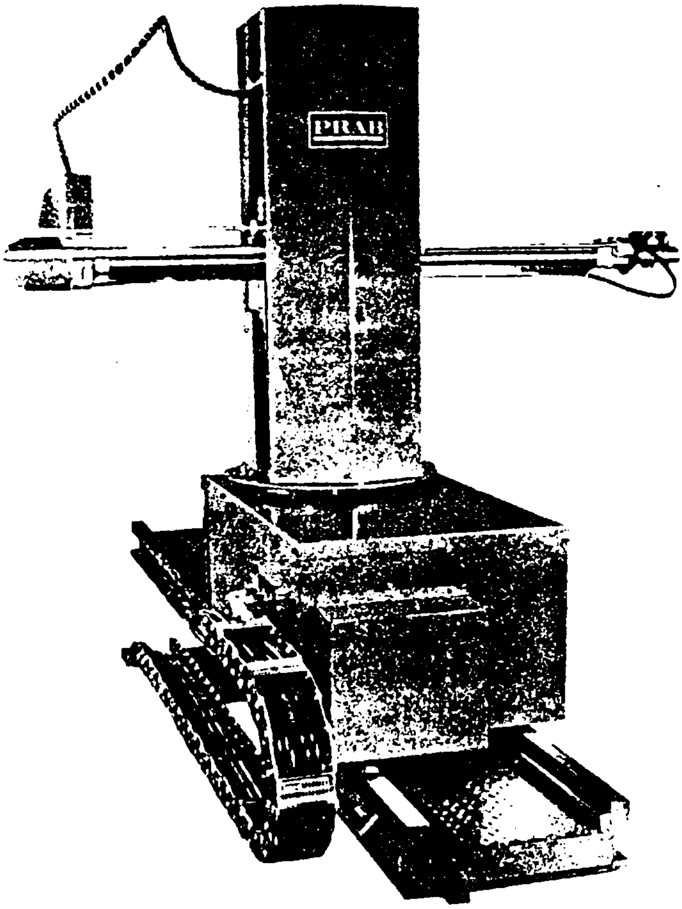


EXHIBIT 3
PAGE 2 OF 2

ROBOT CONFIGURATIONS: CYLINDRICAL



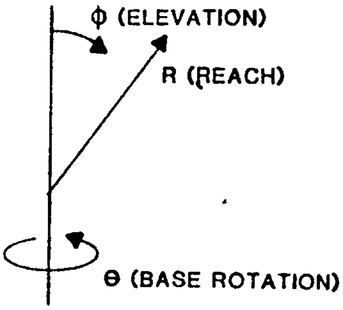
EXAMPLE OF A CYLINDRICAL COORDINATE ROBOT:
PRAB MODEL E ROBOT, WITH 7 AXES OF MOTION
(PHOTO COURTESY OF PRAB ROBOTS, INC.)

EXHIBIT 4
PAGE 1 OF 2

ROBOT CONFIGURATIONS: SPHERICAL

COORDINATE SYSTEM

SPHERICAL



TYPICAL ROBOT DESIGN

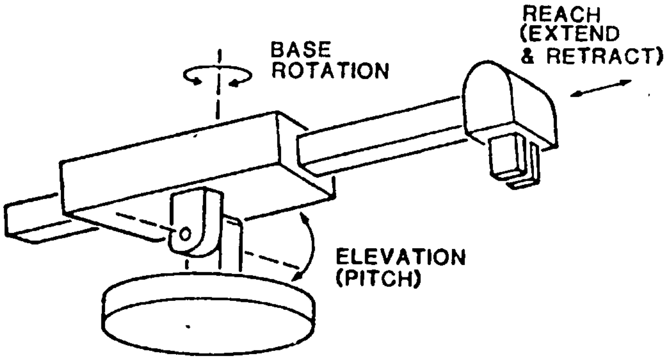
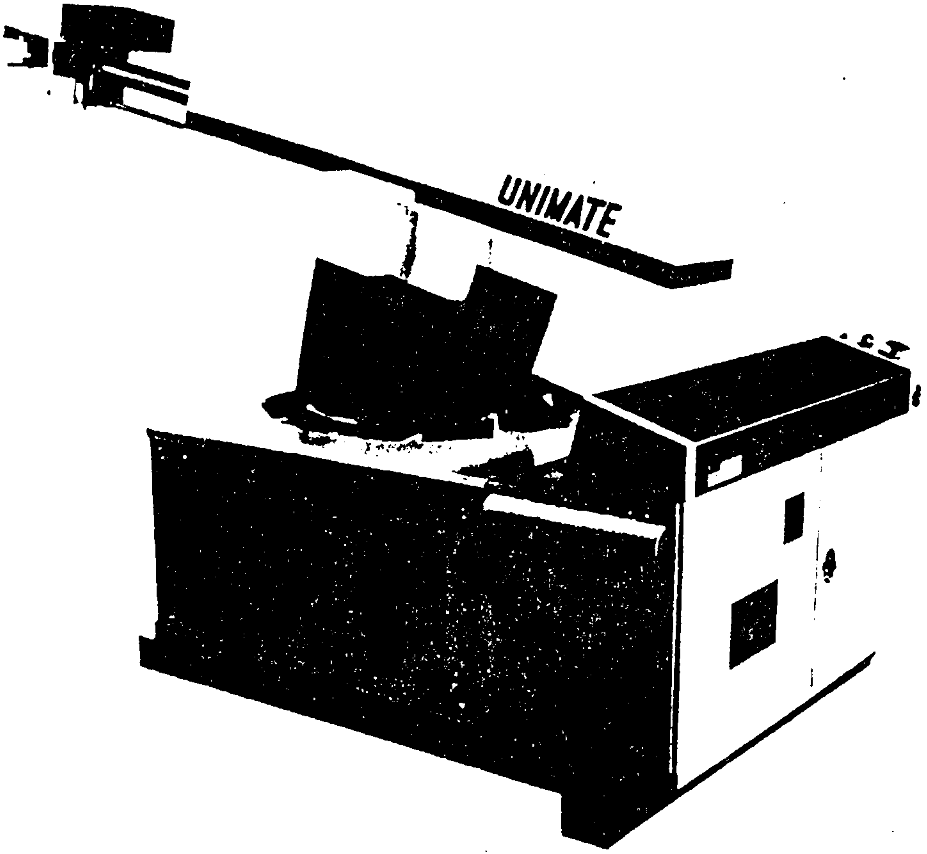


EXHIBIT 4
PAGE 2 OF 2

ROBOT CONFIGURATIONS: SPHERICAL



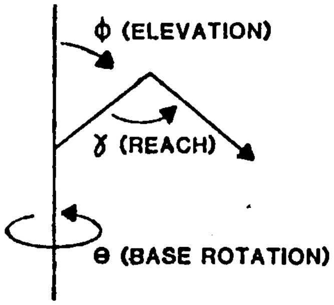
EXAMPLE OF SPHERICAL COORDINATE ROBOT: UNIMATE 1000 SPHERICAL COORDINATE ROBOT (PHOTOGRAPH COURTESY OF UNIMATION, INC.)

EXHIBIT 5
PAGE 1 OF 2

ROBOT CONFIGURATIONS: JOINTED ARM

COORDINATE SYSTEM

JOINTED



TYPICAL ROBOT DESIGN

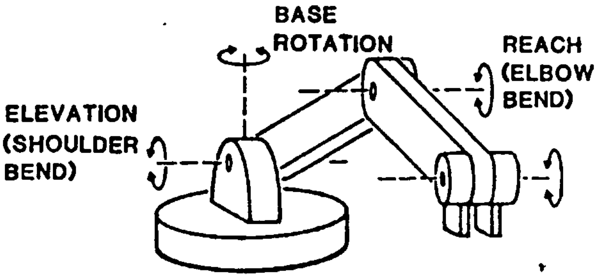
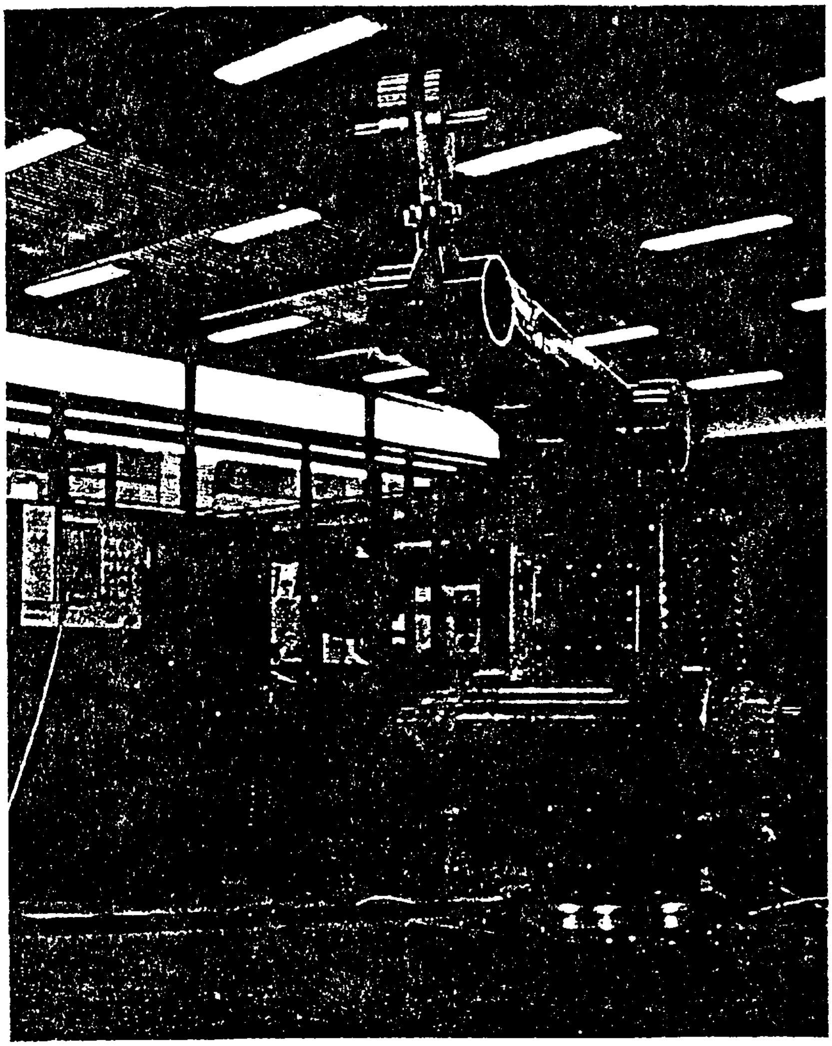


EXHIBIT 5
PAGE 2 OF 2

ROBOT CONFIGURATIONS: JOINTED ARM



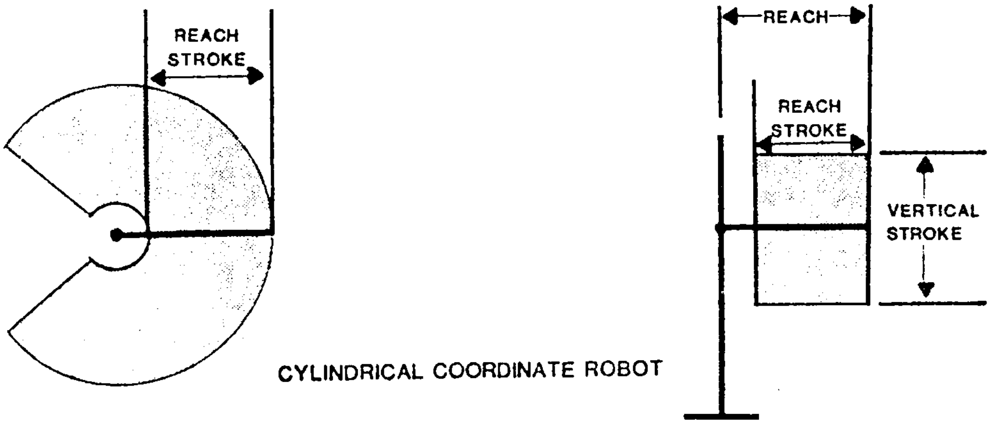
EXAMPLE OF JOINTED ARM ROBOT ASEA IRb-60 ROBOT (PHOTOGRAPH COURTESY OF ASEA, INC.)

ROBOT WORK ENVELOPES

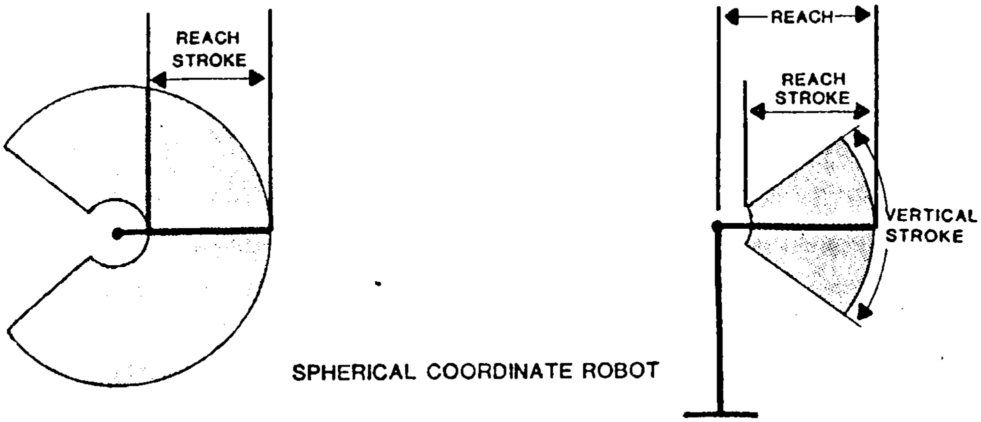
EXHIBIT 6

TOP VIEW

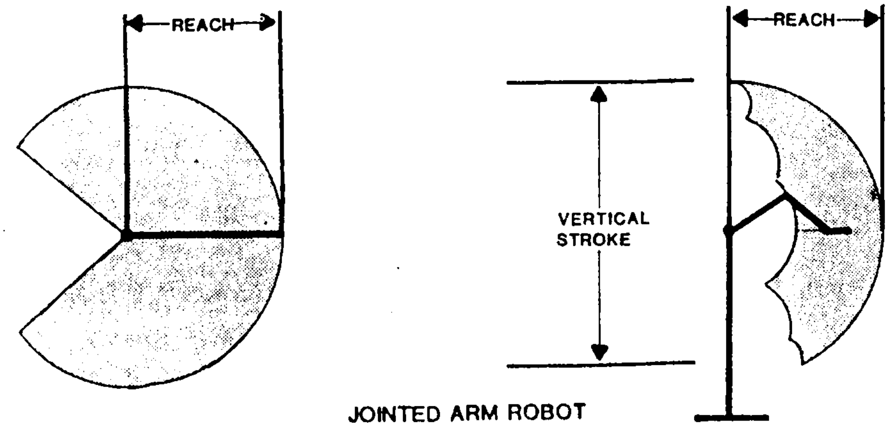
SECTIONAL SIDE VIEW



CYLINDRICAL COORDINATE ROBOT



SPHERICAL COORDINATE ROBOT



JOINTED ARM ROBOT

about a vertical axis to trace the outline of a sphere.

The jointed-arm coordinate robot has a manipulator that most closely resembles a human arm. Two arm members are connected to each other, and one arm is connected to a base. The arms are connected by "elbow" and "shoulder" joints to provide three rotational motions. When the wrist is connected to the lower arm an additional three "degrees of freedom" are provided. The wrist axes allow "roll" (rotation in a plane perpendicular to the end of the arm), "pitch" (vertical rotation around the end of the arm), and "yaw" (horizontal rotation around the end of the arm). The resulting motion at the end of the wrist traces an irregular shape that roughly approximates a sphere.

The jointed-arm robot has a total of six degrees of freedom available for motion. In general, industrial robots may have as few as two and as many as eight degrees of freedom. Typical robots in industrial applications have five or six degrees of freedom. A seventh degree of freedom can be achieved by mounting the robot on a movable track (on the floor or overhead), and an eighth is achieved if the track allows motion of the robot in two directions. In summary, a typical six degrees of freedom robot has three axes of motion provided by the arm, and an additional three axes provided by the wrist.

Manipulator Arm Operation

The manipulator arm is basically a series of mechanical linkages and joints that move in a specified sequence. The function of the arm is to bring the end effector to a specified point in space. This motion is accomplished by one of three types of drive systems: hydraulic, electric, or pneumatic. The arm mechanisms are driven by several actuators which may be pneumatic or hydraulic cyclinders, hydraulic rotary actuators, or electric motors. These actuators either drive the links directly, or they indirectly drive them through gears, chains, or ball screws. In the case of hydraulic or pneumatic drives, valves mounted on the manipulator control the flow of air or oil to the actuators.

Hydraulically driven robots have the advantage of mechanical simplicity, strength, and high speed. Electrically actuated robots, most of which are driven by DC servo motors, are generally not as fast or as strong as hydraulic robots, but they tend to be more accurate and can repeat sequences of operations with higher precision. Also, since no hydraulic power unit is required, they save floor space. Pneumatically driven robots are generally used for small "pick and place" type of operations.

In addition to actuators, each link of the manipulator arm has a feedback device which keeps the controller informed of its position. The type of feedback mechanism used can range from a simple limit switch actuated by the manipulator arm to various position measuring devices, such as encoders, resolvers, potentiometers, or tachometers. The type used depends upon several factors, such as the type of movement or the desired resolution. These feedback devices are the internal sensors used by the robot controller to gather information by which to generate signals to move the end effector through space.

End Effectors

An end effector is installed on the mounting surface of the wrist. This is the tooling used to perform the robot's task. The term end effector refers to a gripper (used to grasp a part), a tool held by a gripper, or a tool mounted directly on the wrist. An end effector is typically used for one of three basic operations: (1) Grasping and manipulating a workpiece; (2) performing a manufacturing operations, such as drilling, spraying, or welding; and (3) sensing the position or shape of an item. Most end effectors are designed for a specific application and are provided by the user. However, an increasing number of standard gripper designs are being offered by manufacturers.

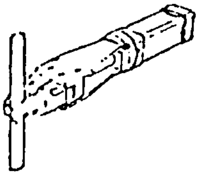
A tremendous variety of gripper and tool designs can be used on industrial robots. Grippers are used either to manipulate parts or to hold tools that perform manufacturing operations. Many grippers contain their own actuators to allow relatively complex manipulation and positioning of objects. Although grippers are normally custom designed, three basic categories are currently in use: mechanical, magnetic, or vacuum (using suction cups). Mechanical grippers hold an object by exerting pressure on the part (friction) or by gently placing solid material around the object to physically constrain it from moving. The types of mechanical linkages used include jaw grippers and finger grippers. Jaw type grippers contact the object by bringing two flat surfaces together, either in parallel or at an angle. Finger type mechanical grippers include two-fingered, three-fingered, or multi-fingered devices.

Vacuum and magnetic grippers use attraction as the means of securing an object. Vacuum, or suction cup grippers, are especially useful in applications where flat pieces of material must be moved, such as sheet glass. For grasping irregularly shaped objects, magnets or suction cups are normally attached in arrays on specially shaped mountings.

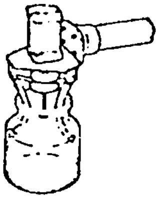
A small sample of the many types of grippers used today is illustrated in Exhibit 7. In addition, a variety of tools can be attached to the manipulator, such as spotwelding guns, routers, sanders, spray guns, ladles, drills, grinders, and heating torches. In designing end effectors, it is important to take into account the weight of the tool or gripper and its effect on the load carrying capacity of the manipulator arm. Secondly, the size and shape of the end effector must be considered in determining the ability of the manipulator to maneuver around equipment or other obstacles.

EXHIBIT 7

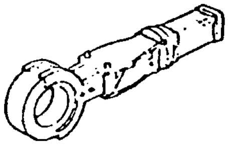
SAMPLE ROBOT GRIPPERS



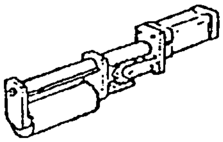
For small diameters



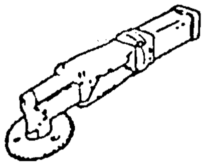
Internal, 3 fingers



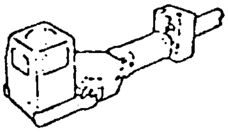
Fitted to the diameter



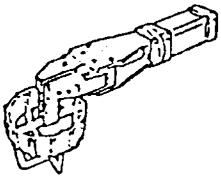
Fitted to the length



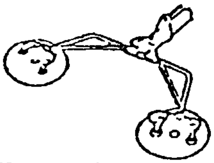
Internal



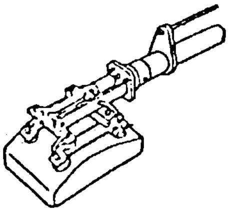
For large objects



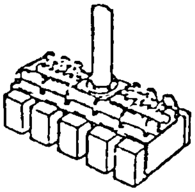
For cast parts



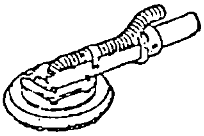
Vacuum, double



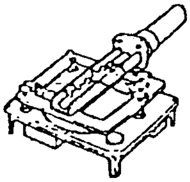
Vacuum, curved surface



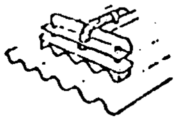
Vacuum, several parts



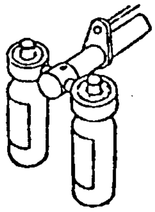
Vacuum pad, several parts



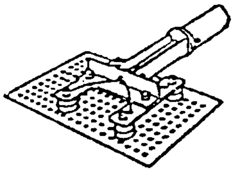
Vacuum, record player



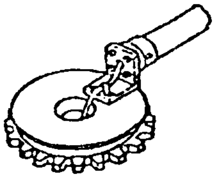
Vacuum corrugated surface



Balloon lifter, bottles



Magnet lifter



Magnet lifter

CONTROLLER

The control unit is the "brain of the robot". The basic function of the controller is to direct the motion of the end effector so that it is both positioned and oriented correctly in space over time. The controller stores the required sequence of motions of the manipulator arm and end effector in a memory. When requested by an operator, it directs the manipulator through the programmed sequence of motions. At the same time, it interacts with the manipulator and other machines connected with the robot through a series of feedback devices to insure that the correct motions are being followed.

A variety of robot controllers are available. Robot control can be accomplished through the use of a stepping drum programmer, a pneumatic logic sequencer, a diode matrix board, an electronic sequencer, a microprocessor, or a minicomputer. The controller may be integrated into the manipulator arm or it may be a separate unit.

Motion of the manipulator is controlled through the various control valves and position monitoring feedback devices located on the arm links. The controller continually monitors position, orientation, speed, and acceleration of the end effector and directs it through its operating cycle.

Categories of Robot Control

There are several ways in which industrial robots can be classified, including the type of coordinate systems upon which the mechanical configurations are based, the type of applications for which the robots are used, or the general level of sophistication of the technology. The most commonly employed, and technically correct, approach to classifying industrial robots is according to the type of control used to direct its motions:

- Non-servo robots, often referred to as "pick and place", "limited sequence", or "end point" robots, rely on an open loop system for control, in which robot motion is controlled by mechanical stops. These robots move on each axis between two positions (end points) only, although it is possible in some cases to activate intermediate stops on certain axes. The mechanical stops are adjustable so that the movement can vary according to the task to be performed. Although non-servo robots provide relatively high speed operation, a high degree of reliability, and a high degree of accuracy when sequences are repeated, they are limited to performing relatively simple tasks, such as transporting parts from one area to another. Typical non-servo robots available in the U.S. include Auto-Place, Seiko, Prab, and Mobot.

- Point-to-point servo robots are controlled by a closed loop servo system, in which the position of a robot axis is measured by feedback devices and compared with a predetermined point stored in the controller's memory. If there is a difference, the controller will command a servo valve in the axis to open and allow the flow of fluid to an actuator, which then moves the axis to the correct postion. The feedback devices then send new position data back to the controller, and further position corrections are then made as required. Servo robots are capable of executing smooth motions with controlled speeds and accelerations. The point-to-point servo robot is one that is controlled with servo valves, but moves in a series of steps from one point to another. The controller can stop each axis at one of any number of points along its axis rather than at only two points, as in the case of non-servo robots. Thus, the manipulative capability of these robots is greatly enhanced. Controllers for these robots include electronic sequencers, mini-computers, microprocessors, and solid state electronic memory devices.

Point-to-point servo robots are represented by some of the largest robots available. The great majority of robots in use today fall into this category. They are used in a wide variety of industrial applications, including material handling, machinery, assembly, and others. Typical robots available in the U.S. in this category include ASEA, Cincinnati Milacron, Unimate, Armax, and several others.

- Continuous path servo robots differ from point-to-point servo robots in that the entire path followed by each axis is programmed on a constant time base during teaching, which means that every motion programmed into the robot will be recorded and played back in exactly the same way. In the case of a point-to-point servo robot, only the end points for each motion are stored in memory, while the particular path that will be followed in arriving at each point is not. The continuous path servo robot follows a smooth, continuous motion. Because of the large number of positions stored in memory, a greater memory capacity is required for continuous than for point-to-point robots. Continuous robots are generally smaller and can achieve higher end-of-arm speeds than point-to-point robots. They are typically used in manufacturing operations where the particular path followed by the end effector is of special importance, such as in spray painting, polishing, arc welding, and other spraying operations. Typical continuous path servo robots available in the U.S. include Cybotech, Nordson, Binks, DeVilbiss/Trallfa, and Thermwood.

To summarize: non-servo robots are controlled by directing each axis to move between two end points, using an open loop (non-feedback) system. Servo robots use feedback devices on the axes of the manipulator to measure and control the position of the axis at any point within its range. Point-to-point servo robots are programmed to move from one point to another, with a large number of steps possible within a cycle. Continuous path servo robots move along a specified, precisely determined path with a smooth, continuous motion.

Programming

In order for the controller to be able to direct the motions of the manipulator, the operator must first tell the controller what to do. The process of programming the controller is referred to as "teaching" the robot. There are three basic approaches that can be used to program an industrial robot:

- Manual - Typically used for programming non-servo robots, manual programming is generally associated with controllers that have mechanical, pneumatic, or electrical memories. In this approach, the robot is programmed by physically presetting the cams on a rotating stepping drum, setting limit switches on the axes, arranging wires, or fitting air tubes. This approach is feasible for less sophisticated robots that move through only a few steps in their operating cycles.

- Leadthrough - In the case of more sophisticated robots using electronic memories in the controllers, the robot can be "taught" by leading it through the operating sequence by means of a control console or hand-held control box (teach pendant). The robot manipulator is led through each step, and the motion is recorded in memory at the end of each movement. This approach is typically used for programming point-to-point servo robots.

- Walkthrough - Typically used for programming continuous path robots, this approach requires the programmer to manually move the manipulator through a complete operating cycle. These motions are then recorded in memory exactly as they were performed by the operator. This approach requires little knowledge of robotics by the operator, but it requires a great deal of skill in performing the operation which is being taught to the robot. Spray painting and welding are two good examples of operations in which walkthrough programming is used.

- Off-Line Programming - Similar to the type of programming used for part programming in numerical control machining operations, off-line programming involves the development of a program on a computer using a higher level programming language. The program is then entered into the robot controller's memory. In this way, the amount of robot downtime is reduced during teaching. The disadvantage of this approach is that it is difficult to write programs that take into account the positioning in space of the manipulator relative to separate objects in its vicinity. However, it is expected that off-line programming, which is currently used in less than 10% of industrial robot applications, will increase significantly in usage in the future.

Memory

The robot memory or data storage is an integral component of the controller. It stores the programs and then gives commands to the robot through the controller. The type of memory used is important, since it determines the way in which commands are stored. Memory devices can be as simple as mechanical step sequencers such as rotating drums. There may also be pneumatic devices such as patch boards or diode matrices, or more sophisticated electronic memories, such as microprocessor devices (ROM, RAM, magnetic tape, or floppy discs). Generally, the degree of sophistication of the memory is consistent with that of the controller and with that of the robot itself.

Interfacing

Most robots need to interact with other machines, transfer lines or parts from outside of its immediate environment. For example, a robot cannot transfer a part until an input signal has been received by the robot that the part has arrived at the initial position. Once the robot has successfully transferred the part to the end position, it must move clear of the conveyor line and signal to the line that the next part can be sent to the initial position. Input and output signals can be provided in several ways, such as electrical, pneumatic, or electronic signals. It is in the area of interfacing that external sensing capabilities can play a role. Tactile (touch) sensors, proximity detectors, force feedback devices, and vision sensors can all be used in applications in which the robot requires data on the location or position of a part, such as in unloading pallets.

Note that these external sensors are differentiated from the internal sensors, or feedback devices, which allow servo robot controllers to interface with the robot manipulators. External sensors, which allow the robot controller to interface with equipment and parts from the outside, represent the highest level of robotics technology currently available. They also represent one of the major areas of future developmental activity in the robotics field, as will be discussed in a later chapter.

Sensors

Sensors are not necessary in fixed automation, where every position of an object must be known. In robots, however, motions are much more complex, and so the expense of redesigning tooling to insure precise positioning would be high. The alternative to precise tooling for insuring correct positioning is the use of sensors that can detect certain characteristics of objects through some form of interaction with them. A sensor is simply a feedback device that allows the robot to make changes in its motions based upon information about its external environment.

There are three general tasks that can be performed by sensors:

- Visual inspection - A wide variety of potential applications now performed by humans could be accomplished through the use of sensors that inspect parts or assemblies to insure that the parts are correctly positioned or are not damaged. Visual inspection includes the identification of parts, the detection of defects, the determination of hole size and location, and other applications. Sensors are not normally used for measurement.

- Part location - When hard automation is used, parts must be located and oriented precisely, which can lead to high fixturing costs. Sensors can locate parts and determine their orientation, which greatly reduces this cost. However, the capabilities of sensors to accomplish this are extremely limited. Random parts cannot easily be identified. For example, sensors cannot identify individual parts and orient the robot gripper correctly to pick them up from bins containing randomly stored overlapping parts.

- Control of manipulation - In such complex operations as assembly or machining, several manipulative operations may be required, such as inserting, twisting, aligning, orienting, and screwing. If each step of the operation is completely controlled, it may be possible to perform the job without sensors. However, the cost would be extremely high. Humans perform these tasks by relying almost entirely on sensors. Similarly, robots can perform them if adequate sensing capability is available to determine when each task has been completed.

The two basic categories of sensors currently available are contact and noncontact. Contact (or tactile) sensors are used to measure force, torque, or to simply detect the existence of an object through touching. Force and torque sensors produce signals upon coming into contact with an object that measure the magnitude of the contact forces. Touch sensors produce signals that indicate the presence of an object, but not the magnitude of a force. Therefore, they tend to be lighter and more sensitive to small forces than force on torque sensors. Contact sensors can be used in such applications as part insertion, assembly operations, packaging, collision avoidance, and machining operations. A variety of transducers are used for force sensors, such as strain gage, magnetic, or piezoelectric transducers. Ideally, a force sensor should measure all three components of force as well as all three components of torque. At the present time, the capabilities of commercially available contact sensors are rather limited. More developmental work is required before force or touch sensors become widely used.

Noncontact sensors are used to determine the characteristics of an object (location, shape, etc.) without coming into direct contact with the object. Three basic types of noncontact sensors are available:

- <u>Proximity sensors</u> - This type of noncontact sensor determines when one object is close to another object. Close is normally defined as a distance ranging from several inches to a few millimeters. Proximity sensors normally do not measure the actual distance, but simply detect the presence of the objects. Commercially available proximity sensors are based upon optical or infrared light detection, magnetic field detection, ultrasound detection, or electrostatic detection.

- Range sensors - A range sensor can be used to measure the distance from the sensor to an object. This can be accomplished using television cameras that measure the distance through triangulation. Another approach is the use of a laser interferometric gage, which is precise but expensive, difficult to use, and sensitive to environmental conditions. Another relatively new approach is the use of an acoustic range finder based upon the sonar principle. In general, very few commercially available range sensors exist.

- Vision sensors - The most potentially useful type of sensor is that based upon visual feedback. The use of visual sensors can greatly reduce the need for jigs and fixtures, and it can ease part tolerances. Vision sensors can be used to recognize parts and to measure characteristics of the parts. Standard television cameras are often interfaced with computers for part recognition. The difficulty is in translating the information received from the sensor into useful information for the robot. Many research organizations, such as Stanford Research Institute, are conducting extensive amounts of research on the problem of developing a low cost, effective visual sensor. The primary applications of visual sensors are to recognize and identify a part by studying its shape, to determine the orientation of a part (on a conveyor belt, for example), and to measure the specific position of an object so that the manipulator arm can move to it. Within the next five years, low cost, effective vision sensors should be widely available.

Power Supply

The third basic component of an industrial robot (the other two are the manipulator and the controller) is the source of energy that drives the manipulator's actuators. The type of power supply required is generally a function of the type of actuators used in the manipulator arm axes. The power system of a robot must be considered in choosing a type of robot, since the performance and capabilities of each type vary according to the type of application being considered. Electrically powered robots tend to run quieter than others, and their motors can be enclosed and protected from dirty environments. Pneumatically powered robots are generally used in light duty applications requiring fast operation. Hydraulically powered robots tend to be stronger than others. They are also more accurate, since hydraulic fluid is not compressible.

The power supply for electrically driven robots simply functions to regulate the incoming electricity. Pneumatically powered robots usually receive power from a remote compressor which may also supply power to other machines. In the case of hydraulic robots, a hydraulic power system can be either an integral part of the manipulator or a separate unit.

ROBOT PERFORMANCE CHARACTERISTICS

The previous sections described the basic physical structure of an industrial robot and the types of applications in which it is used. The purpose of those sections was to tell what a robot is and what it does. In this section, the parameters by which the performance of a robot is measured are defined. These characteristics represent some of the more important considerations that a robot purchaser needs to study when deciding on what type of robot to select for a particular application.

In general, an industrial robot must satisfy three basic requirements. First, it must be flexible. By definition, a robot is not a dedicated machine, but rather offers the advantage of being "multifunctional", as discussed earlier. Therefore, a robot should be capable of being used in several manufacturing operations.

Secondly, an industrial robot must be reliable. The advantage of high utilization because of a high degree of flexibility will be lost if the robot is out of service often for maintenance or repairs. Reliability means a relatively low requirement for maintenance, dependable operation requiring few repairs, and the ability to function satisfactorily in a hostile operating environment (e.g., high temperatures or corrosion).

Finally, a robot must be easily programmed. Since a robot can be used for many different variations of manufacturing tasks, it is likely to require constant reprogramming to change its operating cycle. Because programming causes a certain amount of downtime, it is essential that a minimum amount of time be devoted to this actvity. This is one reason that the use of off-line programming is likely to increase in the future.

In addition to these basic general requirements, there are several specific performance characteristics that should be understood and analyzed when considering the purchase of a robot:

- <u>Positioning accuracy</u> - This is a measurement of the ability of the manipulator to position the end effector (tool or gripper) at a specified point ordered by the controller. Accuracy is specified as a range (e.g., ± .020") around a target point within which the end effector center is expected to position itself upon receiving a command. Accuracy is a meaningful measurement only in the case of computer controlled systems where the control system has to calculate a position and then command the manipulator to move there. In the case of a "tape recorder" mode, in which the control system simply records positions during teaching, and then plays them back during operation, accuracy is not a consideration. In the case of a spray painting (continuous path) robot using a walkthrough teach program, for example, once the initial sequence is programmed, the important consideration is whether the manipulator can reach the same position again. This is known as repeatability.

- Repeatability - Most manufacturers and users are more concerned about this measurement, which specifies how well the manipulator is able to reach a specified position over and over again. A repeatability of ± .010", for example, means that once a certain position has been reached by the end effector, it can be assumed that during the next cycle the end effector will reach a position that is within .010" of the original position.

- Reliability (Uptime) - The reliability of a robot is normally specified as the percentage of time during which the robot can be expected to be operating normally (i.e., not out of service for maintenance or repairs). In general, reliability for industrial robots is very good, with typical estimates of 96-98% uptime claimed by robot manufacturers. In most cases, robot users have found that these estimates are correct.

- Mean time before failure - This is a measure of the estimated number of hours that a robot is expected to operate until it encounters its first failure requiring downtime. Most manufacturers claim a time of between 200 and 800 hours for their robots, with some estimates ranging as high as 2,000 hours.

- Payload capacity - The amount of weight that an industrial robot can carry during operation is an important consideration in determining the size of robot required. The payload capacity is the maximum weight that can be carried by a robot at low speed (given as a percentage of maximum speed), and at normal operating speed. These numbers typically range from just one or two pounds up to well over 2,000 pounds.

- End of arm speed - This is a difficult measurement to accurately define, because of the variations in arm movement, positioning, and load being carried. However, it is useful to compare the speeds with which robots can move an object from one point to another and back again. Typical speeds of current robots are in the range of 30-60 inches per second. Non-servo robots tend to be somewhat faster than servo robots.

- Memory Capacity - The memory capacity of a servo robot controller is an important feature, since it determines the length and complexity of the operating cycle which can be performed. Non-servo robots do not possess a memory as it is normally defined. Memory capacity is defined by the number of steps or motions which can be performed during one operating cycle. Most commercially available robots offer up to several hundred steps (or "points") in storage capacity. In this way, the motion of a point-to-point robot can be programmed so precisely that the movement of the manipulator arm looks like that of a continuous robot.

These performance characteristics, along with several other robot attributes, are summarized in Exhibit 8, which shows a comparison of the three basic categories of robots discussed in this chapter.

EXHIBIT 8

TYPICAL CHARACTERISTICS OF BASIC ROBOT TYPES

ROBOT CATEGORY

		SERVO	
	NON-SERVO	POINT-TO-POINT	CONTINUOUS
PRICE RANGE	$5,000-40,000	$30,000-90,000	$50,000-130,000
DEGREES OF FREEDOM	2-5	5-6	5-6
CONFIGURATION:			
RECTANGULAR	●		
CYLINDRICAL		●	
SPHERICAL		●	
JOINTED ARM		●	●
PAYLOAD CAPACITY (LBS.)	2-100	UP TO SEVERAL HUNDRED	10-30
END OF ARM SPEED (IN./SEC.)	40-50	30-40	40-50
MEMORY	MECHANICAL STEP SEQUENCER AIR LOGIC MICROPROCESSOR	MICROPROCESSOR	MICROPROCESSOR
MEMORY CAPACITY	20-100 STEPS	SEVERAL HUNDRED	0.5-2 HOURS
PROGRAMMING:			
MANUAL	●		
LEADTHROUGH		●	
WALKTHROUGH			●
POWER:			
HYDRAULIC		●	●
PNEUMATIC	●		
ELECTRIC	●	●	●
POSITIONING ACCURACY (±IN.)	± .010	± .040	± .100
REPEATABILITY (±IN.)	± .010	± .040	± .100
RELIABILITY (% UPTIME)	97%	96%	95%
TYPICAL APPLICATIONS:			
MATERIAL HANDLING	●	●	
MACHINE LOADING		●	
SPRAYING		●	●
WELDING		●	
MACHINING		●	
ASSEMBLY	●	●	
INSPECTION	●	●	

COMMERCIAL ROBOTS

There are as many as 100-150 different models of industrial robots currently available in the U.S. With the market growing at a rate of 35-50% per year, new companies are regularly entering the business with new robots. Presently, there are over 50 companies involved in manufacturing or distributing robots in the U.S., and one-fourth of these companies have been in this business for less than two years.

The robotics industry is experiencing such dynamic growth that it is almost impossible for robot users to keep abreast of the changes. New models are being introduced, old ones are being deleted, and new technological developments are expanding potential robot applications. Robots are becoming more reliable, stronger, more flexible, more accurate, faster, and their memory capacities are larger. Microprocessors and mini-computers have been incorporated into their design, which enables them to communicate with other computers for program storage and transfer. Improved vision and tactile systems are expanding robotics applications into new areas.

MANUFACTURERS AND MODELS

Although the robot industry is more than two decades old, it is still a relatively small industry, with a current annual sales volume of about 1,500-2,000 robots per year. The market in the U.S. is dominated by six companies that account for about 90-95% of total sales, as shown in the following table:

Company	% of Robot Sales (1981)
Unimation	37%
Cincinnati Milacron	29
ASEA	8
Prab	8
DeVilbiss	7
Copperweld (Auto-Place)	4
Others (40-45%)	7
	100%

During the next two years, as the market continues to expand, it is likely that the percentage of sales accounted for by other companies will increase considerably. However, Unimation and Cincinnati Milacron will continue to be the industry leaders for some time. Brief profiles of the five leading companies in the industry are presented in the following sections.

Unimation, Inc.

Unimation Inc., the largest robot manufacturer in the U.S., is a subsidiary of Condec Corporation, which is a high technology manufacturer of a number of industrial products.

Joseph F. Engelberger, who is the President of Unimation, Inc., is often referred to as the "father of industrial robots." He started the business in 1958 and delivered his first robot to General Motors Corporation in 1961. These early models sold for approximately $25,000, but cost around $60,000 to manufacture. As a result, it was not until 1974 that Unimation, Inc. turned a profit. To date, Unimation has installed over 3,600 robots and is now producing 55-65 robots per month. The company manufactures eight different models. The hydraulic models are the tank turret type, have from 3-6 axes and are capable of lifting from 50 to 450 lbs. Typical applications include welding, foundry work, forging and material handling.

The electric motor models include a portable and versatile welding robot and three models for small parts handling and assembly operations. They are the jointed arm type robot, have 5-6 axes of freedom and lift from 2-5 lbs. Typical applications include material handling, assembly, and inspection operations.

Cincinnati Milacron

Cincinnati Milacron's Industrial Robot Division is the second largest manufacturer of robots in the U.S., and appears to be increasing its share of the market relative to Unimation. Cincinnati Milacron, a very large and diversified company, is a world leader in the production of machine tool systems for the metalworking and plastic processing industries. The company developed its first industrial robot in 1969. Three years later it broke the tradition of spherical coordinate robots by developing one of the first jointed arm computer controlled robots called the 6CH Arm. Presently, Cincinnati Milacron manufactures two hydraulically operated computer controlled robots. The T3, which means "The Tomorrow Tool", is a 6 axis jointed arm robot capable of lifting 100 pounds. It is a highly maneuverable robot capable of performing many applications, such as spot, seam and arc welding, foundry work, assembly and many material handling jobs. The second model is the HT3, which is a heavy duty version of the T3. It has a load carrying capacity of 225 pounds and is used in similar jobs as the T3. In addition, a new robot called the T3R3 (three rolled wrist) is available in the $70,000-$80,000 price range for performing more complex jobs, such as assembly.

ASEA, Inc.

ASEA, Inc. is part of a large multi-national company headquartered in Sweden. The parent company (ASEA AB) has about 100 subsidiaries in 36 countries, and is involved in six broad areas of business. ASEA, Inc., has its U.S. headquarters in White Plains, New York, from which it distributes two basic models of industrial robots.

Both models are point-to-point servo controlled, have up to six degrees of freedom, and have electric drives. The smaller model can lift up to 13.2 pounds, and the other can lift 132 pounds. These robots have a broad range of applications, including material handling, machining, machine loading/unloading, welding, and others. ASEA, which has been in the robot business since 1972, is considered by many users to have the top of the line robots for grinding and deburring applications. ASEA robots are also very reliable, with up to 1,000 hours claimed for a mean time before failure.

Prab Robots, Inc.

Prab Robots, Inc., with about 8% of the robot market in the U.S., ranks with ASEA in relative importance. Prab Conveyors, Inc., Kalamazoo, MI, was founded 30 years ago and today is the leading supplier of metal scrap handling conveyor and processing systems. Prab has just recently purchased two plants totaling 75,000 square feet of floor space into which it plans to move its robot manufacturing, sales, and engineering, during the first quarter of 1982. Starting in 1981, Prab decided to aggressively market its robots by forming a separate robot division. The robot division is now Prab Robots, Inc., and Prab

Conveyors, Inc., is a wholly-owned subsidiary. The company has also entered into a licensing agreement with Can-Eng Manufacturing Ltd., of Niagara Falls, Ontario, Canada for the manufacture of the eight Prab industrial robot models.

Prab Robots, Inc., produces two different robot lines. The first which was introduced in 1968, is a line of medium technology, non-servo robots. There are two basic turret type models which vary only in reach and weight handling capacity. These robots have 5 axes, are hydraulically operated, have either a drum memory or microprocessor, and are capable of lifting from 50 to 125 lbs.

Prab's second line of industrial robots is the Versatran Robot, which was acquired from AMF, Inc. in 1979. The Versatran Robot line was introduced in 1958 and is considered to be a high technology robot. Four models are available. These cylindrical coordinate robots are servo controlled, have up to seven degrees of freedom and can lift up to 2,000 lbs. They are primarily hydraulically driven, although Prab has just recently added an option of electric motors to the wrist axes.

Prab's robots have been applied in many jobs, including machine loading/unloading, die casting, forging and material handling.

DeVilbiss

DeVilbiss, which was founded in 1886, developed one of the first spray painting guns for Henry Ford during the early 1900's.

DeVilbiss first became involved with an industrial painting robot in about 1970 through a European affiliate. In 1974 the company developed an agreement to market the Trallfa robot in the U.S. with Unimation, which was a distributor for the Norwegian based Trallfa robot at that time. In 1976, DeVilbiss signed an agreement with the Trallfa Company directly to market the Trallfa robot exclusively in North America. In 1980, an agreement was signed with Trallfa to manufacture its robot in the U.S. Presently, there are over 900 Trallfa painting robots installed worldwide, and 150 of them are in the U.S.

The Trallfa robot is a continuous path, servo controlled, hydraulically operated, six degrees of freedom robot which has the capability to expand to three additional axes when greater freedom of movement is required. The robot is capable of continuous path and point-to-point programming with programs stored on floppy discs. Although designed primarily as a painting robot, it is capable of welding, pick and place, stapling and hot melt or bead flowing operations. A typical price for this robot with controller is $90,000-$100,000.

Other Companies

The remainder of the market is shared by over 40 companies of various sizes. Many companies are manufacturing high technology, low cost robots and will be competing for a larger share of the market.

One of the more significant companies to recently enter the robot field is the General Electric Company. GE began marketing an Italian robot called the Allegro about two years ago. It has 3 to 5 degrees of freedom, electric motor drives, and a multi-microprocessor control system that can lift a payload of 14 pounds. Additionally, GE has begun to market another line of robots this year. There are three models, including an arc welding robot (AW7), a spraying robot (S6), and a process robot (P5). The arc welding model is a computer controlled, hydraulically operated robot which interfaces with a positioning table. The spraying model is a computer controlled, hydraulically operated, 6 axis robot. The process model is a computer controlled, 5 degrees of freedom, electric motor driven robot with a load capacity of 22 pounds.

A new company which has entered the robotic field is International Robomation/Intelligence, of Carlsbad, California. The company offers one model called The Affordable Robot which will sell for less than $10,000. Evaluation units will be available for installation during the first quarter of 1982, and production deliveries will begin in the second quarter. This robot is a high technology model using multi-microprocessor controls and air-servo motors for movements. It has 5 degrees of freedom, each controlled by its own microprocessor, it has an arm reach of 78", and it can lift 50 pounds.

Another new company entering the industrial robot industry is Hodges Robotics International Corporation, of Lansing, MI. Hodges was formed two years ago and until recently produced custom mobile robotic units for hazardous environments such as Three Mile Island, bomb squads, fire departments, and the military. The first commercially available industrial model, the MRZ-5, is a six axes, computer controlled, pneumatic and stepping motor drive robot capable of lifting 50 pounds and sells for $47,500.

GCA Corporation, of Bedford, Mass., has recently introduced a six axes robot. GCA entered the robotics industry by acquiring PaR Systems, which has for over 20 years been designing and manufacturing remotely controlled equipment used to handle, inspect and store hazardous materials. PaR systems has designed several programmable automated systems, including a 30,000 pound capacity overhead robot used by the metal processing industry. The newest industrial robot model, the XR 6100, is a 6 axes, computer controlled, electric motor drive robot capable of lifting 100 pounds.

Another promising new company is Cybotech Inc., of Indianapolis. Cybotech was formed through a joint venture between Ransburg Corp. (U.S.) and Renault (France). Cybotech produces several point-to-point servo robots with up to 175 pound payloads. These robots are generally considered to be of high quality, but also high priced. In addition, Cybotech offers a high quality spray painting robot in the $130,000 price range.

A detailed listing of most of the robot models available in the U.S. today is presented in Exhibit 9, including manufacturer names, specifications, and typical applications. In addition to these manufacturers, a potentially significant impact could be made by large companies that have developed robots for internal use, such as Texas Instruments and IBM. Both companies have substantial capabilities in the area of computer technology, which is an area of great interest in the robotics field today. The combination of these technologies could lead to a significant interest in the robotics field by large computer companies.

SERVICES

Most robot manufacturers started producing robots as an off-shoot of some other business, primarily the machine tool and automated equipment businesses. Like the numerical control (NC) machine tool industry, robot manufacturers offer a variety of services, which range from a simple piece of specialized equipment to a complete turnkey robot system. A summary of the typical services provided by each robot manufacturer is provided in Exhibit 10.

A turnkey robotic system can include a feasibility study, applications engineering services, robot installation, programming, checkout, interfacing with other equipment, gripper fabrication and

EXHIBIT 9

SPECIFICATIONS OF COMMERCIAL ROBOTS

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COMPANY MODEL SPECIFICATIONS	ADVANCED ROBOTIC			ARMAX ROBOTICS				ASEA	
	750 CYRO	CYRO II	820 CYRO	LC	VC	LJ	VJ	IRB6	IRB60
NUMBER OF AXES	5	6	5	247	3-7	4-9	5-9	3-6	3-6
WORK ENVELOPE									
HORIZONTAL REACH (In.)	39	79		56	65	78	78	34	51
VERTICAL REACH (In.)	30	79		55	83	94	127	47	85
COORDINATE SYSTEM									
RECTANGULAR	x	x							
CYLINDRICAL									
SPHERICAL									
JOINTED ARM			x					x	x
END-EFFECTOR TOOLING									
VACUUM								x	x
PARALLEL									
CUSTOM	WELD	WELD	WELD					MAG	MAG
MAXIMUM PAYLOAD (lbs.)	50	500	22	150	150	150	150	13	132
DRIVE TRAIN									
HYDRAULIC									
PNEUMATIC									
ELECTRIC MOTORS	x	x	x					x	x
POSITIONAL ACCURACY (±In.)	.008	.016	.012					.008	.012
REPEATABILITY (±In.)	.008	.016	.012					.002	.005
CONTROL									
NON-SERVO									
SERVO-POINT TO POINT								x	x
CONTINUOUS	x	x	x					x	x
PROGRAMMING METHOD									
MANUAL									
LEADTHROUGH	x	x							
TEACH	x	x	x					x	x
CRT/KEYBOARD	x	x							
MEMORY TYPE									
AIR LOGIC									
MECHANICAL									
TAPE/DISC	x	x	x					x	x
SEMI CONDUCTOR	x	x	x					x	x
PRICE ($000)	99	140	75	60	60	60	60	75	102
APPLICATIONS									
PAINTING									
WELDING	x	x	x					x	x
MACHINING	x		x					x	x
FOUNDRY/DIE CAST								x	x
MACHINE LOADING		x						x	x
MATERIAL HANDLING		x						x	x
ASSEMBLY	x	x	x					x	x
INSPECTION	x	x	x					x	x

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SPECIFICATIONS OF COMMERCIAL ROBOTS

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COMPANY	AUTOMATIX	CINCINNATI MILACRON		COPPERWELD ROBOTICS		CYBOTECH CORP.			
MODEL SPECIFICATIONS	AID800	T 3	HT 3	AP10	AP50	H80	V80	G80	P15
NUMBER OF AXES	5	6	6	4	4	6	6	6	7
WORK ENVELOPE									
HORIZONTAL REACH (In.)	38	97	102	12	18	87	87	118-Y 197-X	110
VERTICAL REACH (In.)	44	154	156	2	5	63	87	39	130
COORDINATE SYSTEM									
RECTANGULAR								x	
CYLINDRICAL				x	x	x			
SPHERICAL									
JOINTED ARM	x	x	x				x		x
END-EFFECTOR TOOLING									
VACUUM		x	x	x	x				
PARALLEL		x	x	x	x				
CUSTOM	WELD	SEV	SEV			x	x	x	x
MAXIMUM PAYLOAD (lbs.)	22	100	225	5	30	175	175	175	33
DRIVE TRAIN									
HYDRAULIC		x	x			x	x	x	x
PNEUMATIC				x	x				
ELECTRIC MOTORS	x								
POSITIONAL ACCURACY (±In.)						.020	.020	.020	.40
REPEATABILITY (±In.)	.008	.053	.050	.003	.010	.008	.008	.008	.20
CONTROL									
NON-SERVO									
SERVO-POINT TO POINT		x	x	x	x	x	x	x	x
CONTINUOUS	x					x	x	x	x
PROGRAMMING METHOD									
MANUAL				x	x				
LEADTHROUGH									
TEACH	x	x	x	x	x	x	x	x	x
CRT/KEYBOARD	x	x	x			x	x	x	x
MEMORY TYPE									
AIR LOGIC									
MECHANICAL									
TAPE/DISC	x					x	x	x	x
SEMI CONDUCTOR	x	x	x	x	x	x	x	x	x
PRICE ($000)	80-95	651	70	161	221	162	151	225	141
APPLICATIONS									
PAINTING									x
WELDING	x	x	x			x	x	x	
MACHINING		x	x			x	x	x	
FOUNDRY/DIE CAST		x	x						
MACHINE LOADING		x	x						
MATERIAL HANDLING	x	x	x	x	x	x	x	x	
ASSEMBLY	x	x	x	x	x				
INSPECTION	x	x	x			x	x	x	

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SPECIFICATIONS OF COMMERCIAL ROBOTS

COMPANY	CYBOTECH CORP. (con't)		DeVILBISS	GAMETICS		GCA	GENERAL ELECTRIC		
MODEL SPECIFICATIONS	V30	H8	TR3003	524	536	XR-6100	P5	S6	AW7
NUMBER OF AXES	8	5	6	5	5	6	5	6	5
WORK ENVELOPE									
HORIZONTAL REACH (In.)	71	33	38				38	52	39
VERTICAL REACH (In.)	118	44	80				44	122	43
COORDINATE SYSTEM									
RECTANGULAR						x			x
CYLINDRICAL		x		x	x				
SPHERICAL						x			
JOINTED ARM	x		x				x	x	
END-EFFECTOR TOOLING									
VACUUM									
PARALLEL									
CUSTOM	x	x	PAINT	x	x			PAINT	WELD
MAXIMUM PAYLOAD (lbs.)	65	17	50	50	250		22		
DRIVE TRAIN									
HYDRAULIC	x		x	x	x			x	x
PNEUMATIC									
ELECTRIC MOTORS		x				x	x		
POSITIONAL ACCURACY (±In.)	.020	.020	.250	.03	.05				
REPEATABILITY (±In.)	.008	.004	.040	.03	.05		.008		.040
CONTROL									
NON-SERVO									
SERVO-POINT TO POINT	x	x	x	x	x	x			x
CONTINUOUS	x	x	x				x	x	
PROGRAMMING METHOD									
MANUAL									
LEADTHROUGH			x						
TEACH	x	x	x	x	x	x	x	x	x
CRT/KEYBOARD	x	x		x	x	x			
MEMORY TYPE									
AIR LOGIC									
MECHANICAL									
TAPE/DISC	x	x	x	x	x	x	x	x	x
SEMI CONDUCTOR	x	x	x	x	x	x	x	x	x
PRICE ($000)		75	100	50	55				
APPLICATIONS									
PAINTING			x			x		x	
WELDING	x	x	x			x	x		x
MACHINING		x				x	x		
FOUNDRY/DIE CAST			x						
MACHINE LOADING			x	x	x				
MATERIAL HANDLING	x	x	x	x	x	x			
ASSEMBLY		x	x			x			
INSPECTION		x	x						

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SPECIFICATIONS OF COMMERCIAL ROBOTS

COMPANY	GENERAL NUMERIC CORP.				HOBART BROTHERS	HODGES	INDUSTRIAL AUTOMATES
MODEL SPECIFICATIONS	MO	M-1	M-3	AO	MOTOMAN-L10	MRZ5	
NUMBER OF AXES					5	6	5
WORK ENVELOPE							
HORIZONTAL REACH (In.)					32	18	24
VERTICAL REACH (In.)					37	72	14
COORDINATE SYSTEM							
RECTANGULAR							
CYLINDRICAL	x	x	x	x			
SPHERICAL						x	
JOINTED ARM					x		
END-EFFECTOR TOOLING							
VACUUM							x
PARALLEL	x	x	x	x			x
CUSTOM					WELD		x
MAXIMUM PAYLOAD (lbs.)	22	44	110	11	22	50 &75	10
DRIVE TRAIN							
HYDRAULIC							x
PNEUMATIC						x	x
ELECTRIC MOTORS					x	x	
POSITIONAL ACCURACY (±In.)					.015		
REPEATABILITY (±In.)	.02	.039	.039	.002	.008	.020	.001
CONTROL							
NON-SERVO							x
SERVO-POINT TO POINT	x	x	x	x	x		
CONTINUOUS		x				x	
PROGRAMMING METHOD							
MANUAL							
LEADTHROUGH							
TEACH	x	x	x	x	x	x	
CRT/KEYBOARD		x	x	x			
MEMORY TYPE							
AIR LOGIC							x
MECHANICAL							
TAPE/DISC					x		
SEMI CONDUCTOR	x	x	x	x	x		x
PRICE ($000)	24	27	79	40	85	47.5	13.5
APPLICATIONS							
PAINTING						x	
WELDING					x	x	
MACHINING							
FOUNDRY/DIE CAST						x	x
MACHINE LOADING	x	x	x				x
MATERIAL HANDLING	x	x	x			x	x
ASSEMBLY				x			
INSPECTION							

SPECIFICATIONS OF COMMERCIAL ROBOTS

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COMPANY MODEL SPECIFICATIONS	I.R.I.	I.S.I.	LYNCH	MANCA	MOBOT	OKAMURA			NORDSON
			EZ HAND-LER 1	MODULAR	MODULAR	RC-04	RC-07AR	RC-08AR	
NUMBER OF AXES	5		4-6			5	5	5	6
WORK ENVELOPE									
HORIZONTAL REACH (In.)	78		48	49	180	20	59	39	• 39
VERTICAL REACH (In.)			24	49	96	5	71	39	110
COORDINATE SYSTEM									
RECTANGULAR		x	x	x	x				
CYLINDRICAL		x		x	x	x			
SPHERICAL		x		x	x				
JOINTED ARM	x	x		x	x		x	x	x
END-EFFECTOR TOOLING									
VACUUM		x		x	x				
PARALLEL		x		x	x				
CUSTOM		x	x	x	x				PAINT
MAXIMUM PAYLOAD (lbs.)	50	200	300	3740	600	11	240	132	20
DRIVE TRAIN									
HYDRAULIC		VARIES	x	x	x		x	x	
PNEUMATIC	x			x	x	x			
ELECTRIC MOTORS					x				
POSITIONAL ACCURACY (±in.)					.005				.100
REPEATABILITY (±in.)	.040	.005	.125	.003	.005	.020	.200	.040	.100
CONTROL									
NON-SERVO				x	x	x			
SERVO-POINT TO POINT	x	x			x		x	x	
CONTINUOUS					x				x
PROGRAMMING METHOD									
MANUAL		VARIES							
LEADTHROUGH				x					
TEACH	x			x	x	x			x
CRT/KEYBOARD	x								
MEMORY TYPE									
AIR LOGIC									
MECHANICAL						x			
TAPE/DISC	x		x		x				
SEMI CONDUCTOR	x		x	x	x		x	x	x
PRICE ($000)	10	25		15	25				110
APPLICATIONS									
PAINTING									x
WELDING		x			x				
MACHINING									
FOUNDRY/DIE CAST		x			x				
MACHINE LOADING	x	x		x	x				
MATERIAL HANDLING		x	x	x	x	x	x	x	
ASSEMBLY				x	x				
INSPECTION		x							

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SPECIFICATIONS OF COMMERCIAL ROBOTS

COMPANY	PRAB/VERSATRAN						REIS		
MODEL SPECIFICATIONS	4200	5800	E	FA	FB	FC	RR515	RR625	RR650
NUMBER OF AXES	5	5	7	7	7	7	5-6	6	6
WORK ENVELOPE									
HORIZONTAL REACH (In.)	43	59	3	60	60	60		134	
VERTICAL REACH (In.)			42	60	60	60		47	
COORDINATE SYSTEM									
RECTANGULAR									
CYLINDRICAL			x	x	x	x		x	x
SPHERICAL	x	x					x		
JOINTED ARM							x	x	x
END-EFFECTOR TOOLING									
VACUUM			x	x	x	x	x	x	x
PARALLEL	x	x					x	x	x
CUSTOM	x	x					x	x	x
MAXIMUM PAYLOAD (lbs.)	75/125	50/100	100	250	600	2000	35	55	110
DRIVE TRAIN									
HYDRAULIC	x	x	x	x	x	x			
PNEUMATIC									
ELECTRIC MOTORS			x	x	x	x	x	x	x
POSITIONAL ACCURACY (±in.)							.008	.025	.025
REPEATABILITY (±in.)	.008	.008	.030	.050	.050	.080		.020	.020
CONTROL									
NON-SERVO	x	x							
SERVO - POINT TO POINT			x	x	x	x	x	x	x
CONTINUOUS							x	x	x
PROGRAMMING METHOD									
MANUAL									
LEADTHROUGH									
TEACH			x	x	x	x	x	x	x
CRT/KEYBOARD									
MEMORY TYPE									
AIR LOGIC									
MECHANICAL	x	x	x	x	x	x			
TAPE/DISC			x	x	x	x	x	x	x
SEMI CONDUCTOR	x	x	x	x	x	x	x	x	x
PRICE ($000)	28	30	50	60	65	100	40	55	60
APPLICATIONS							+		
PAINTING							x		
WELDING			x	x	x	x	x		
MACHINING							x		
FOUNDRY/DIE CAST	x	x	x	x	x	x		x	x
MACHINE LOADING	x	x	x	x	x	x	x	x	x
MATERIAL HANDLING	x	x	x	x	x	x	x	x	x
ASSEMBLY								x	x
INSPECTION							x	x	x

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SPECIFICATIONS OF COMMERCIAL ROBOTS

COMPANY	RIMROCK	ROB-CON	ROBOTICS		SEIKO INSTRUMENTS			
MODEL SPECIFICATIONS	MOD.995	PACE III	LJ	VJ	100	200	400	700
NUMBER OF AXES	3	3-6	4-9	5-9	2/3	2/3	2/3	4
WORK ENVELOPE								
HORIZONTAL REACH (in.)	80	48	78	78	1		28	10
VERTICAL REACH (in.)		24	94	127	2	.39-1	4	2
COORDINATE SYSTEM								
RECTANGULAR	x				x		x	
CYLINDRICAL		x				x		x
SPHERICAL			x	x				
JOINTED ARM								
END-EFFECTOR TOOLING								
VACUUM					x	x	x	x
PARALLEL					x	x	x	x
CUSTOM	x	x	x	x	x	x	x	x
MAXIMUM PAYLOAD (lbs.)	40	100	150	150	3.3	1.7	8.8	2.2
DRIVE TRAIN								
HYDRAULIC	x	x	x	x				
PNEUMATIC					x	x	x	x
ELECTRIC MOTORS								
POSITIONAL ACCURACY (±in.)					.0004	.0004	.001	.001
REPEATABILITY (±in.)	.020	.030			.0004	.0004	.001	.001
CONTROL								
NON-SERVO	x		x	x	x	x	x	x
SERVO-POINT TO POINT			x	x				
CONTINUOUS								
PROGRAMMING METHOD								
MANUAL		x						
LEADTHROUGH								
TEACH	x		x	x	x	x	x	x
CRT/KEYBOARD			x	x				
MEMORY TYPE								
AIR LOGIC					x	x	x	x
MECHANICAL	x				x	x	x	x
TAPE/DISC					x	x	x	x
SEMI CONDUCTOR			x	x	x	x	x	x
PRICE ($000)	25-70		80	60	5	5	9	7.5
APPLICATIONS								
PAINTING								
WELDING			x	x				
MACHINING			x	x			x	x
FOUNDRY/DIE CAST	x	x						
MACHINE LOADING			x	x	x	x	x	x
MATERIAL HANDLING			x	x	x	x	x	x
ASSEMBLY					x	x	x	x
INSPECTION			x	x	x	x	x	x

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SPECIFICATIONS OF COMMERCIAL ROBOTS

COMPANY	STERLING-DETROIT CO.		THERMWOOD			UNIMATION			
MODEL SPECIFICATIONS	U ROBOT ARM	SYSTEM II	SER3	SER6	SER7	1000	2000	4000	8000
NUMBER OF AXES	5	6	5	6	6	3-5	5-6	5-6	5-6
WORK ENVELOPE									
HORIZONTAL REACH (in.)	120			48	39	42	41	52	
VERTICAL REACH (in.)	72			84	76				
COORDINATE SYSTEM									
RECTANGULAR	x	x							
CYLINDRICAL									
SPHERICAL						x	x	x	x
JOINTED ARM			x	x	x				
END-EFFECTOR TOOLING									
VACUUM	x	x							
PARALLEL									
CUSTOM	x	x	x	PAINT	x	x	x	x	x
MAXIMUM PAYLOAD (lbs.)	150	150	50	18	25	50	200	450	200
DRIVE TRAIN									
HYDRAULIC	x	x	x	x	x	x	x	x	
PNEUMATIC									
ELECTRIC MOTORS									
POSITIONAL ACCURACY (±in.)									
REPEATABILITY (±in.)	.005	.005	.080	.125	.080	.050	.050	.080	.050
CONTROL									
NON-SERVO	x	x							
SERVO-POINT TO POINT						x	x	x	x
CONTINUOUS			x	x	x				x
PROGRAMMING METHOD									
MANUAL									
LEADTHROUGH				x	x				
TEACH	x	x	x			x	x	x	x
CRT/KEYBOARD									x
MEMORY TYPE									
AIR LOGIC									
MECHANICAL	x								
TAPE/DISC				x		x	x	x	x
SEMI CONDUCTOR		x	x	x	x	x	x	x	x
PRICE ($000)	20-60		32	47		28	55	70	59
APPLICATIONS									
PAINTING				x					
WELDING			x				x	x	x
MACHINING									
FOUNDRY/DIE CAST	x	x				x	x	x	x
MACHINE LOADING	x	x				x	x	x	x
MATERIAL HANDLING	x	x	x		x	x	x	x	x
ASSEMBLY		x							
INSPECTION									

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SPECIFICATIONS OF COMMERCIAL ROBOTS

COMPANY	UNIMATION	(con't)		U.S. ROBOT
MODEL SPECIFICATIONS	9000	PUMA'S	APPRENTICE	MAKER
NUMBER OF AXES	5-6	5-6	5	5
WORK ENVELOPE				
HORIZONTAL REACH (In.)		16/34	64	36
VERTICAL REACH (In.)		16/34	45	36
COORDINATE SYSTEM				
RECTANGULAR				
CYLINDRICAL				
SPHERICAL	x			x
JOINTED ARM		x		
END-EFFECTOR TOOLING				
VACUUM				x
PARALLEL				
CUSTOM	x	x	WELD	
MAXIMUM PAYLOAD (lbs.)	450	2/5		5
DRIVE TRAIN				
HYDRAULIC				
PNEUMATIC				
ELECTRIC MOTORS		x	x	x
POSITIONAL ACCURACY (±In.)				
REPEATABILITY (±In.)	.080	.002/.004	.040	.004
CONTROL				
NON-SERVO				
SERVO-POINT TO POINT	x	x		
CONTINUOUS	x	x		x
PROGRAMMING METHOD				
MANUAL				
LEADTHROUGH			x	
TEACH	x	x	x	x
CRT/KEYBOARD	x	x		x
MEMORY TYPE				
AIR LOGIC				
MECHANICAL				
TAPE/DISC	x	x		
SEMI CONDUCTOR	x	x	x	x
PRICE ($000)		41/47	38	34
APPLICATIONS				
PAINTING				x
WELDING	x	x	x	x
MACHINING				
FOUNDRY/DIE CAST	x			
MACHINE LOADING	x	x		x
MATERIAL HANDLING	x			x
ASSEMBLY		x		x
INSPECTION				x

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ROBOT MANUFACTURERS AND SERVICES

SERVICES / ROBOT MANUFACTURER	DEMONSTRATIONS	TRAINING PROGRAMS	LEASES	WARRANTIES MONTHS	SERVICE CONTRACTS	U.S. SERVICE CENTERS	DELIVERY TIME (WEEKS)	FIRST INSTALLATION	TOTAL NUMBER INSTALLED
ADVANCED ROBOTIC CORP.	YES	YES	YES	12	YES	5	26		85
AMERICAN ROBOT CORP.		YES	NO	3	YES			1981	
ASEA		YES	YES	12	YES	2	20	1973	1000
AUTOMATION CORP.	YES	NO	YES	12	YES	1	16-20	0	
AUTOMATIX INC.	YES	YES	YES	3	YES	5	8-12	1980	12+
BINKS	YES	YES	NO	12	YES	2	STOCK	1975	1
CINCINNATI MILACRON		YES	YES	12	NO	12		1973	
COPPERWELD ROBOTICS	YES	YES	YES	12	YES	2	12	1968	
CYBOTECH CORP.	YES	YES	YES	12	YES	1	24-36	1975	300
DeVILBISS CO.	YES	YES	YES	12	YES	9	12-14	1972	900+
GALLAHER ENTERPRISES	YES	YES	NO	3	YES	1	12	1981	0
GAMETICS	NO	YES	NO	12	NO	1	16-20	1972	27
GCA CORP.-PAR SYSTEMS	YES	YES	NO	12	YES		24	1970	
GENERAL ELECTRIC	YES	YES	YES	12	YES	62	8	1975	251
GENERAL NUMERIC CORP.	YES	YES	NO	12	YES	10	16-20	1973	
HOBART BROTHERS	YES	YES	YES	12	YES	2	20	1980	500
HODGES	YES	YES	YES	12-36	YES	2	8	1981	2
INDUSTRIAL AUTOMATES		NO	NO	6	YES		4	1973	
I.S.I. MFG. INC.	YES	YES	NO	3	YES	2	24	1964	3000+
KULICKET & SOFFA IND.	YES	YES		12	YES	3	10-20	1982	0
MANCA, INC.		NO	NO	6	NO	2	4-6	1970	400+
MOBOT CORP.	NO	YES	YES	12	YES	3	20	1974	102
NORDSON CORP.	YES	YES	RENT	12	NO	1	10-16	1979	50+
PICK-O-MATIC		NO	NO		NO			1974	2000+
PLANET (ARMAX)		YES		12	YES	SEV.	16-24	1956	2+
PRAB ROBOTS		YES	NO	12	NO	3	12-24	1958	800
REIS MACHINES	YES	YES	NO	12	NO	1	16	1981	22
RIMROCK CORP.		YES	NO	6	NO		8-12	1976	140
ROB-CON	YES	YES	NO	12	YES		20-22	1975	40+

EXHIBIT 10
PAGE 2 OF 2

ROBOT MANUFACTURERS AND SERVICES

SERVICES ROBOT MANUFACTURER	DEMONSTRATIONS	TRAINING PROGRAMS	LEASES	WARRANTIES (MONTHS)	SERVICE CONTRACTS	U.S. SERVICE CENTERS	DELIVERY TIME (WEEKS)	FIRST INSTALLATION	TOTAL NUMBER INSTALLED
SEIKO INSTRUMENTS	YES	YES	NO	12	NO	15-20	2	1940 1968	3000+
STERLING-DETROIT CO.	YES	YES	YES	6	NO	1	10-12	1968	510
THERMWOOD		YES	YES	12	NO		14-16	1980	
UNIMATION		YES	YES	12	YES	16	4-20	1961	3600
UNITED STATES ROBOT	YES	YES	YES	12	NO	2	16	1981	5

customer training. Equipment warranties can range from 90 days to one year, with the majority of the robotics systems having warranties of one year. Approximately two-thirds of the robot manufacturers provide various types of hardware service contracts and have an average of 1-3 service centers throughout the U.S. The small number of service centers and the relatively long response time to service requests have encouraged robot users to train their own maintenance personnel. This has worked well in the past with the older, less sophisticated models. However, as robots become more sophisticated in the areas of multi-microprocessor/computer controls and electronic sensors, extensive service networks similar to those of the computer industry will be necessary. The top robot manufacturers have already developed a number of distribution and service centers. The difficulty and expense of setting up an effective distribution and service network will likely become a future market entry barrier for new robot manufacturers.

Presently, the average leadtime for a robot supplier to deliver a robot is in the range of 12-18 weeks. Several companies are attempting to expand their production capacity, but with the demand for robots increasing, it is doubtful that leadtimes will shorten in the near term.

Approximately half of the robot manufacturers offer leasing arrangements and a few even have rental contracts. Leasing is an area which could increase significantly in the future because of the high initial cost of some robotic systems, with initial total purchase costs as high as $200,000. Several major firms other than robot manufacturers are studying the idea of leasing robots. This will allow many of the smaller companies to investigate the possibility of using robots without having to spend large amounts of capital. However, the economics of leasing versus buying should be evaluated very carefully for each application. A typical robot costing $50,000 can have a payback period of less than two years which is usually considered an adequate investment return.

Robot manufacturers have set up training programs which range from 1-7 days and average about 4 days in length. The training programs are oriented toward programming, system operation and maintenance. These training sessions are usually conducted either at the robot manufacturer's facility or at the user's facility. Most robot manufacturers have working models at their facilities for both demonstrations and training programs. These training programs are extremely important for the safety of both personnel and equipment. If the equipment is operated incorrectly, it can easily be damaged. In addition, robots can make unexpected, fast movements which can strike other equipment or personnel.

INDUSTRIAL ROBOT APPLICATIONS

The number of different applications for which industrial robots can be used is even more diverse than the number of different models of robots that are available. Their usage is more a function of the characteristics of the manufacturing process than the nature of the products being produced, and so they are used in a variety of different industries.

The specific applications in which robots are being employed are those where robots have been proven to offer certain advantages over manual labor or hard automation. Generally, robots offer advantages in manufacturing processes characterized by a high degree of order, simplicity, repetition, and moderate production volumes. As a result, industrial robots are used in machine loading and unloading, material handling operations, welding, spray painting, stacking and unstacking parts, machining, and many other applications.

POTENTIAL ROBOT APPLICATIONS

In Chapter 1, robots were reviewed from the point of view of what they are (definition, physical structure, components, characteristics). Here they are considered in terms of what they can do. Robots are automated machines that can move and manipulate things repetitively without the assistance of humans. They can be reprogrammed to perform a variety of tasks, and in some cases they can sense their external environment and make adjustments.

These capabilities allow robots to perform a wide variety of tasks normally associated with manual labor. At the same time, they have certain characteristics of hard automation. The range of potential applications, therefore, is quite large. Robots can be used for both processing and part handling operations. Processing operations include those in which a part or assembly is altered in some way by a robot holding a tool, such as in spray painting or welding. The motions required in these applications tend to be fairly complex, and so either a continuous robot (such as the Trallfa used in spray painting) or a point-to-point robot with a large data storage capacity is used.

Part handling operations are those in which parts or assemblies are transported from one location to another. This includes relatively straight forward operations such as the transfer of parts from one conveyor to another, which may require motion in only two or three dimensions. These operations are often performed by non-servo robots, such as the Prab, Seiko, or the Auto-Place. Other part handling applications are more complicated and require varying degrees of manipulative capability, such as machine loading and unloading, palletizing, die casting, and simple assembly. These operations are typically performed by servo controlled point-to-point robots, such as those produced by Unimation, Cincinnati Milacron, ASEA, and others.

Criteria For Using Robots

Since robots can be used in a wide variety of applications in both processing and part handling, it is not the particular manufacturing operation that defines whether or not it makes sense to use a robot. Instead, there are a number of underlying factors which must be considered in each case in evaluating the relative merits of using robots rather than manual labor or dedicated automation. In general, robots tend to offer advantages over humans in the following cases:

- When robots have capabilities that humans do not have.

- When robots can perform a task better than humans (e.g., better accuracy or lower cost).

- When there is a job that should not be done by humans (e.g., because of a safety hazard or because the job is unpleasant).

Generally, the first two situations also apply when comparing robots with hard automation. However, in this case it is the ability of robots to perform tasks normally associated with manual labor that give them certain advantages over hard automation.

As discussed in Chapter 1, robots can be viewed as a type of automated equipment that combines certain characteristics of hard automation and manual labor. The determination of which manufacturing alternative is best in a particular situation requires that three basic criteria be considered:

- Capabilities - What can each alternative do? (And what are the capabilities required by the application?)

- Manufacturing Environment - What is the nature of the environment within which each alternative must perform?

- Performance - How well does each do its job?

Capabilities

In a typical manufacturing plant, three basic operations are performed on objects as they are transformed from raw materials to finished products by various tools. First, they are transported from point-to-point to be stored, machined, assembled, or packaged. Second, they are manipulated. That is, they are inserted, oriented, or twisted in order to be in the proper position for machining, assembly, or some other operation. Third, they are monitored along the way to insure that they are in the proper location, in the correct orientation, of the correct dimensions, and of the correct surface composition.

These tasks can be performed manually or through the use of automated machinery. As shown in Exhibit 11, hard automation has excellent capabilities for transporting items from one location to another. Many early forms of automated equipment were developed to eliminate the need for human transport of objects. Automated equipment can lift heavier objects, move them faster, and work for longer periods of time than can their human counterparts. The other two tasks, however, are still best performed by humans. Humans are capable of complex movements of objects, such as those required in the assembly of a gas regulator. Sensing is also best performed by humans, especially in complex operations such as recognition of shapes. Many manufacturing operations that require the manipulation of parts also require a feedback sensor to allow alternations in a sequence of operations, such as when a part is found to be incorrectly shaped or positioned.

One other capability has not yet been mastered by hard automation. Humans are extremely flexible in their ability to change activities. Hard automation, on the other hand, is completely dedicated to one task. Once programmed or set up, hard automation will perform a specific task over its entire useful life.

The development of industrial robots represents a logical evolution of automated equipment to combine certain features of hard automation and human labor. State-of-the-art robots have manipulative capabilities, limited sensing capabilities, and are versatile enough to be reprogrammed for several different applications. At the same time, they offer the reliability, endurance, and freedom from human involvement of hard automation. In a fully automated factory, all manufacturing operations would be performed by automated equipment,

EXHIBIT 11

COMPARISON OF MANUFACTURING ALTERNATIVES: CAPABILITIES, MANUFACTURING CHARACTERISTICS, AND PERFORMANCE

		HARD AUTOMATION	ROBOTS	MANUAL
CAPABILITIES	TRANSPORT	EXCELLENT	GOOD	LIMITED
	MANIPULATION	NEGLIGIBLE	SIMPLE MANIPULATION	COMPLEX MANIPULATION
	SENSING	NONE	LIMITED SENSING	COMPLEX SENSING
	FLEXIBILITY	NONE	MODERATE	HIGH
MANUFACTURING CHARACTERISTICS WHERE SUITABLE	TYPE OF OPERATION	MASS PRODUCTION	MASS/BATCH	BATCH/JOB SHOP
	NUMBER OF SHIFTS	2-3	2-3	1
	COMPLEXITY OF TASK	LOW	MEDIUM	HIGH
	DEGREE OF STRUCTURE	HIGH	HIGH	LOW
	PRODUCTION VOLUME	LONG RUN	MEDIUM RUN	SHORT RUN
	PRODUCTION RATE	HIGH SPEED	SLOW SPEED	SLOW SPEED
	DEGREE OF HAZARD	NO LIMIT	NO LIMIT	NON-HAZARDOUS ONLY
PERFORMANCE	QUALITY	HIGH	HIGH	MEDIUM
	PRODUCTIVITY	HIGH	MEDIUM	LOW
	OPERATING COSTS	LOWEST FOR LONG RUN, HIGH SPEED PRODUCTION	LOWEST FOR MEDIUM RUN, SLOW SPEED PRODUCTION	LOWEST FOR SHORT RUN, SLOW SPEED PRODUCTION

under the control of a hierarchical computer system. Thus, robots represent the link that could lead to major increases in factory automation in the future. But they will not only replace human workers. Because of the unique combination of capabilities found in robots, they can be used in certain applications now performed manually as well as in some applications now performed by hard automation.

Manufacturing Characteristics

The nature of the manufacturing environment within which a task is performed is a second major consideration in determining the types of applications for which robots are suitable. There are certain environments in which robots tend to be advantageous over either hard automation or manual labor. As seen in Exhibit 11, seven manufacturing characteristics can be examined:

- Type of Operation - A manufacturing operation can be performed in an environment ranging from mass production with little or no change over time to batch or job shop production, with periodic changes in the items being produced. Hard automation, being dedicated to one task, tends to make sense in a mass production environment, while manual labor makes sense in a job shop operation, in which flexibility is required. Robots tend to be suitable for a batch production environment, which represents a large percentage of all American industry today. The primary benefit of robots in batch production is their ability to be easily reprogrammed for the frequent job setups that are required.

- Number of Shifts - The greater the number of shifts, the higher will be the output of production. It is generally easier to justify the use of hard automation in a two or three shift operation than in a one shift operation. Robots are also more appropriate in a two or three shift operation, since the higher productive time tends to offset the relative slowness of the robots. Most robots currently used in machine loading and unloading, for example, are used on a three shift basis. Welding robots are most often used on a two shift basis. Some robots, such as painting robots, are often used on a one shift basis, since the justification for these robots is in the elimination of the unpleasant environment or the improved product quality rather than a higher production volume.

- Complexity of Task - Robots are most suitable for operations that are neither too simple nor too complex. Complexity can be thought of as the number of steps required to complete one operating cycle. Some transport operations may simply require a limit switch to open and close to control the movement of parts. These operations might best be performed by fixed conveying machines, or even simple chutes. At the other extreme, operations which require complex manipulation along with sensing capabilities that judge the orientation or position of a part may be too complex for today's robots. Complex operations are best performed manually.

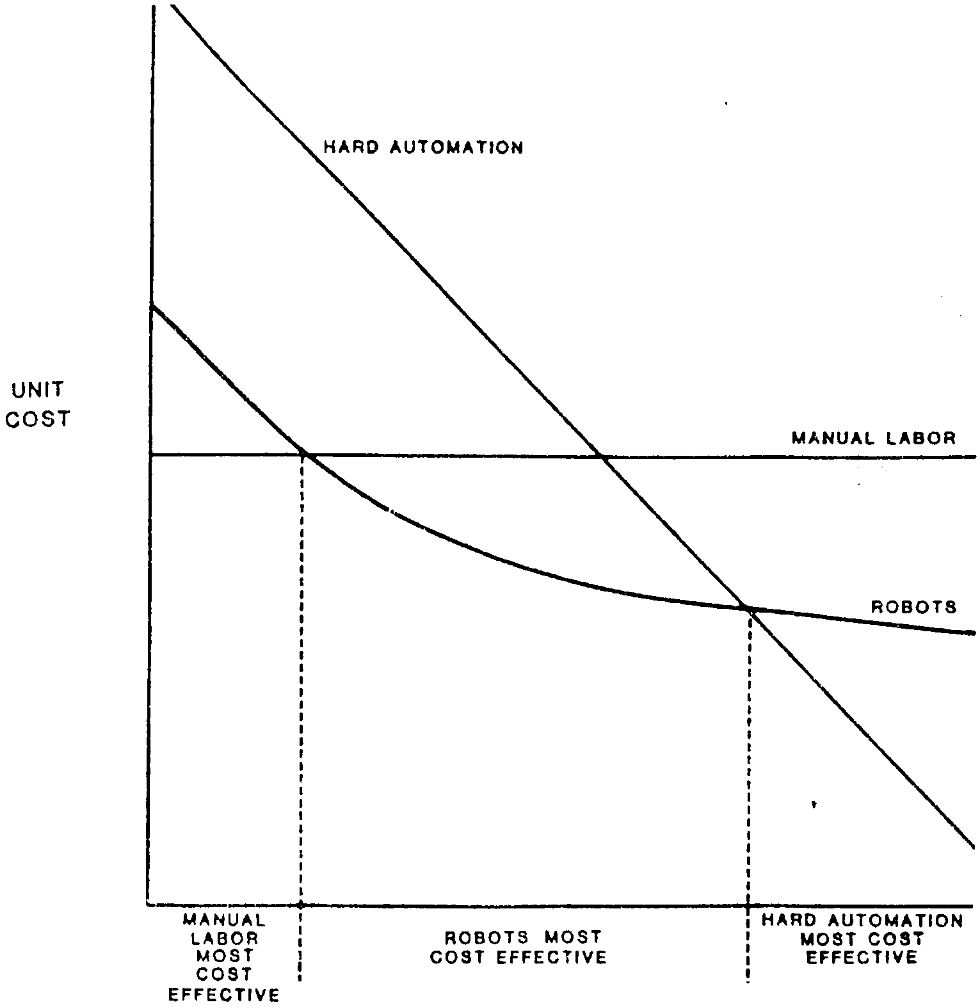
- Degree of Structure - currently available robots, like hard automation, require that the work environment be extremely orderly. Parts need to be presented to a robot in a known location and orientation. There must not be any unanticipated obstacles to interfere with the robot's motion. Sensing capabilities will allow some degree of disorder, but at present, these capabilities are extremely limited. State-of-the-art vision sensors, for example, will allow a robot to correctly orient its gripper to pick up a single part on a conveyor belt. But it cannot identify a part located in a bin of parts. This is another example where current development efforts are attempting to allow robots to expand their capabilities by performing tasks now done by manual labor.

- Production Volume - Robots operate best at "medium" levels of production. In the case of batch production, the batch size is an important consideration in comparing robots with other alternatives. For small batches, robot setup time can become large. Each time a new batch is run, the robot may have to be reprogrammed, part locating devices may need to be readjusted, and end effectors may need to be changed. Ideally, the total setup time should be less than 10% of the production time. In mass production, hard automation tends to be more cost effective at high volumes, while manual labor is more effective at low volumes (see Exhibit 12). For a particular application, the shape of this curve may vary, but there is generally a middle area of production volume where robots are most cost effective.

- Production Rate - Robots generally operate at about the same rate as humans, although small non-servo robots (pick-and-place) may operate at faster speeds. Generally, if the operation requires that a part be picked up, transferred, and placed in less than three seconds, a robot will not be capable of performing the task. End of arm speeds of 40-50 inches per second are available, but positioning accuracy tends to decrease as speeds increase. The increase in productivity resulting from the use of a robot does not come about because of higher speeds, but rather in the much higher percentage of time during which a robot performs useful work. There are no lunch breaks, coffee breaks, vacations, or sick days. Robot users have experienced downtimes due to maintenance or repairs of only about 4%. As an example of productive time, it has been

EXHIBIT 12

COMPARISON OF MANUFACTURING METHOD UNIT COSTS, BY LEVEL OF PRODUCTION



PRODUCTION VOLUME PER YEAR

found that in a manual arc welding operation, only about 30% of the time is actual welding time. When robots are used, this time increases to 70-90%.

- Degree of Hazard - A major advantage of robots is their ability to perform tasks previously performed by humans in environments that are hazardous. The first major application of robots was in loading and unloading die cast machines, a job that is performed in a high temperature, polluted atmosphere. Robots can also be used in environments that are toxic, that have fumes and vapors, where there is a danger of fire or explosion, where there is potential nuclear radiation, or where there is a potential electrical shock hazard. Spray painting is a good example of an unpleasant task that previously could only be performed by humans.

Performance

In addition to the basic manufacturing tasks that can be performed and the nature of the manufacturing environment where they are performed, a third consideration is how well the task is accomplished. Generally, automated equipment can perform a manufacturing task better than humans. As seen in Exhibit 11, both hard automation and robots generally are capable of achieving better quality and greater productivity than humans. Robots operate more consistently and with greater precision than humans and so can produce high quality workpieces. Robots, like hard automation, can also achieve a higher level of productivity than humans. Although they generally are no faster than humans on a particular task, their ability to work consistently over much longer periods of time than humans allows them to be more productive.

A third measure of performance is operating costs. There are certain cases where manual labor may be less expensive than either hard automation or robots. When the task being performed is part of a batch or job shop manufacturing operation characterized by short production runs, manual labor may be less expensive because of the inefficiencies inherent in setting up hard automation. Also, when the production rate is slow, manual labor may be less expensive. In the case of high speed or long run production, however, automation tends to be less expensive.

Although robots generally will perform better than humans in many operations, the determination that a robot is the best alternative for a particular application assumes that the robot has the capabilities necessary to conduct the operation. The reason hard automation is not used in assembly operations, for example, is that the manipulative and sensing capabilities required for assembly do not exist. Robots, however, offer the high performance associated with hard automation combined with the basic capabilities associated with manual labor. But robot capabilities are still limited. They may be best for certain simple assembly operations but not for more complex operations, for example. In the case of complex assembly, not only is an extremely flexible manipulator arm and gripper required, but programming and memory requirements are high. Furthermore, there is the possibility of loss of production resulting from robot stoppage when defective parts are fed to it. Human workers can easily spot the defective part, discard it, and continue the operation with another part. Robots, however, require a sensing capability (vision, force, or touch) to identify the defective part and alter the operating sequence based upon this feedback. Thus, the expected performance of each alternative is a consideration in determining suitable applications only after reviewing basic capabilities and the characteristics of the manufacturing environment.

Although robots represent a potentially major advance in manufacturing automation, it is unlikely that a completely automated factory will become a reality in the near future. When matching robot performance and capabilities to the manufacturing environment, it is important to consider certain areas where humans will continue to be necessary. The cost of trying to achieve that last 10% of automation can become prohibitively high. Therefore, people should continue to be used where judgment is required. Although the major thrust of current research and development efforts is in the area of sensor design, the ability of robots to use judgment and make decisions is likely to be extremely limited well into the foreseeable future.

Suitable Robot Applications

Based upon these criteria, there are a wide variety of applications in which robots offer advantages over either hard automation or manual labor. In most cases, applications most suitable for robots are those in which certain capabilities of manual labor are required, the high performance of automation is required, and there are certain characteristics of the manufacturing environment that make it desirable to eliminate manual labor. For example, the loading and unloading of a die casting machine is a task requiring human manipulative skills, and it is performed in an unpleasant environment in which humans should not be working. In general, there are seven basic categories of applications for which robots are most suitable, as shown in Exhibit 13.

Material Handling

Non-servo (pick and place) robots are typically used for manufacturing operations that require the movement of objects from one point to another. This includes such applications as transferring parts from one conveyor to another, transferring glass plates (using a suction gripper) from a processing line to a conveyor, palletizing parts into wire baskets, palletizing cereal boxes, transferring sand castings from a casting line to a shake out conveyor, transporting

EXHIBIT 13

MAJOR CATEGORIES OF SUITABLE ROBOT APPLICATIONS AND RATIONALE FOR USING ROBOTS

APPLICATION	EXAMPLES	ROBOT CAPABILITIES JUSTIFYING USE			PRIMARY BENEFITS OF USING ROBOTS			
		TRANSPORT	MANIPULATION	SENSING	IMPROVED PRODUCT QUALITY	INCREASED PRODUCTIVITY	REDUCED COSTS	ELIMINATION OF HAZARDOUS/ UNPLEASANT WORK
MATERIAL HANDLING	PARTS HANDLING PALLETIZING TRANSPORTING HEAT TREATING	●					●	●
MACHINE LOADING	DIE CAST MACHINES AUTOMATIC PRESSES NC MILLING MACHINES LATHES	●	●			●	●	
SPRAYING	SPRAY PAINTING RESIN APPLICATION		●		●		●	●
WELDING	SPOT WELDING ARC WELDING		●			●	●	●
MACHINING	DRILLING DEBURRING GRINDING ROUTING CUTTING FORMING		●	●		●	●	
ASSEMBLY	MATING PARTS FASTENING		●	●		●	●	
INSPECTION	POSITION CONTROL TOLERANCE			●	●			

metal components for heat treating, and many others. This was one of the earliest applications of industrial robots, and is the area where the definition of robot sometimes becomes confused with that of a material handling system.

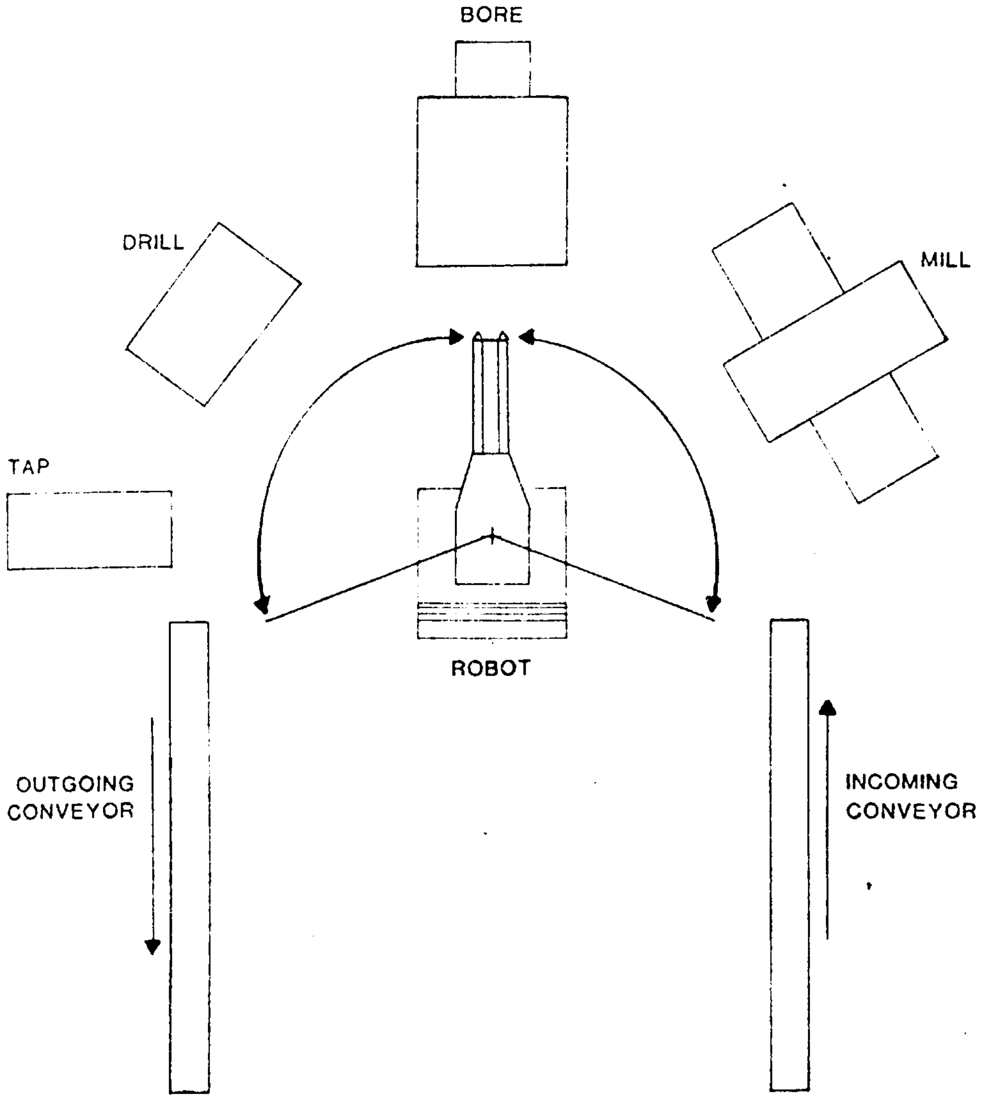
As seen in Exhibit 13, this application makes use of the basic transport capability of robots, with the manipulative capability being of less importance. Motion may take place in only two or three dimensions, with robots mounted either stationary on the floor or on slides that allow it to move from one work station to another. The primary benefits of using robots here are to reduce direct labor costs and to eliminate the need for humans to perform work that may be tedious, exhausting, or hazardous. For example, human labor is undesireable when the objects being transferred are heavy, hot, cold, or chemically hazardous. However, in certain environments, such as when high production volumes are required and there is no manipulation of parts required, hard automation can perform transport functions better than robots. Another benefit of robots is in lower material breakage when handling fragile parts.

Machine Loading

A second, and somewhat more sophisticated category of robot application, is in the area of machine loading and unloading. Robots can be used to grasp a workpiece from a conveyor belt, lift it to a machine, orient it correctly, insert or place it on the machine, then unload it and transfer it to another line. A typical layout for a fully automated work station is shown in Exhibit 14. The greatest efficiency is achieved when a robot is surrounded by several machines, as in this example of group technology. A servo point-to-point robot controls and executes a sequence of four machining operations by unloading a workpiece from an incoming conveyor, and then loading and unloading the workpiece on a milling machine, a boring machine, a drilling machine, and finally a tapping machine. The only robot time not used here is the time spent waiting for each machine to complete

EXHIBIT 14

TYPICAL WORK ARRANGEMENT FOR FULLY AUTOMATED FOUR MACHINE LINE



its operation. An inspection sensor is often included among the machines, along with other secondary tools. The types of sequences that can be programmed are unlimited.

One of the best applications for robot machine loading is in the loading and unloading of a die cast machine. In this case, several other operations, such as quenching and trimming, are also often performed. Other machine loading and unloading applications include:

- Loading and unloading hot billets into forging presses
- Metal removal machine loading and unloading
- Metal stamping press loading and unloading
- Loading and unloading plastic components into plastic injection molding machines
- NC milling machine loading and unloading

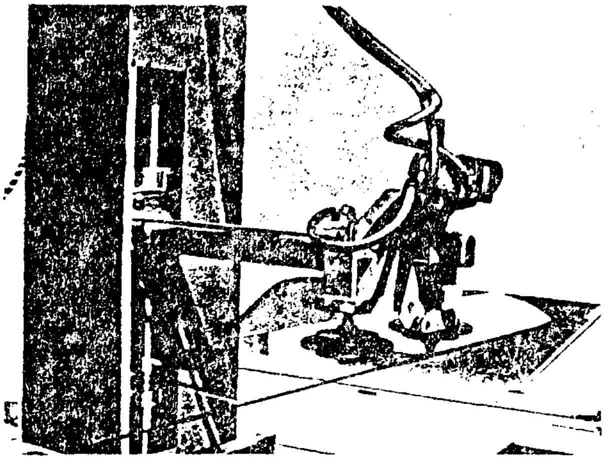
Although adverse temperatures or atmospheres during loading and unloading can make robots advantageous to use in these areas, the primary benefit of using robots here is to reduce direct labor cost by eliminating the need for manual labor. Another major benefit is that productivity is likely to increase because of the higher amount of time during which the robot can work. In machine loading and unloading, it is both the manipulative and transport capabilities that make robot usage feasible. Exhibit 15 shows examples of two Prab robots performing material handling and machine loading/unloading operations.

Spraying

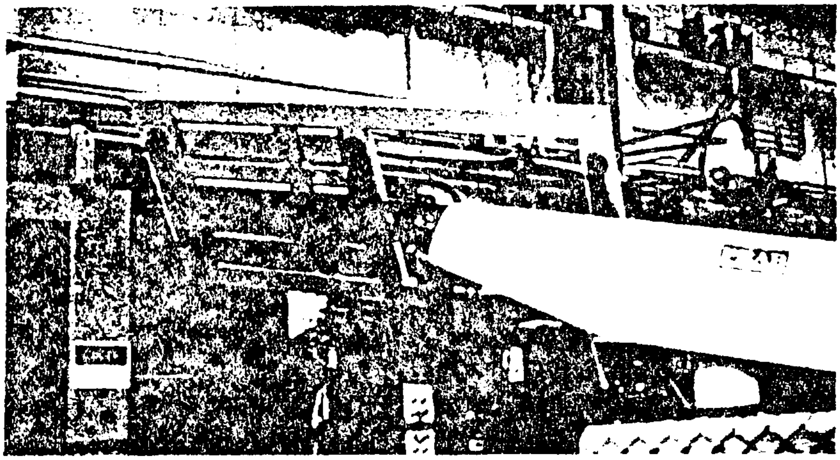
In processing applications, a robot holds a tool and acts on a

EXHIBIT 15

EXAMPLES OF MATERIAL HANDLING AND MACHINE LOADING APPLICATIONS OF ROBOTS



A PRAB MODEL E ROBOT STACKS AUTOMOBILE WINDSHIELDS (PHOTOGRAPH COURTESY OF PRAB ROBOTS, INC.)



A PRAB MODEL 4200 ROBOT UNLOADS A PLASTIC DOOR FROM A FOAM MOLDING MACHINE (PHOTOGRAPH COURTESY OF PRAB ROBOTS, INC.)

workpiece to change it in some way. These applications are typically characterized by the need for a precise rate of controlled motion. For this reason, continuous path servo robots are often used. A typical application is the spraying of some material, such as paint, stain, asphalt coating, plastic powder, and other fluid or powdered materials (see Exhibit 16). Robots apply these materials using air, airless, and electrostatic spraying equipment to a wide variety of parts, such as automotive panels, appliances, and furniture. Parts normally enter the spraying area via a moving conveyor line, and the robot's sequence of spraying motions are coordinated with the motion of the conveyor.

The manipulative capability of the robot is of prime importance here. A major benefit of robot usage is higher product quality, through more uniform application of the material and less overshoot. Another benefit is reduced costs, through the elimination of human labor, a higher percentage of time spent on the work, and reduced material waste. A third major benefit is the reduced exposure of humans to toxic materials. Because of these benefits, this is one of the oldest applications of robots.

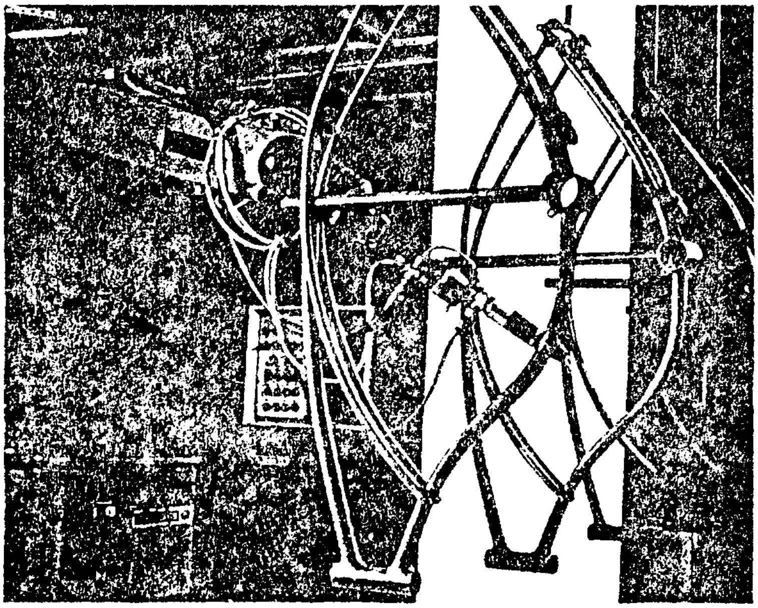
A relatively new application of spraying robots is in the application of plastic resin and chopped glass fiber into molds during the process of producing glass reinforced plastic products. Another new application is the spraying of epoxy resin between successive layers of graphite broadgoods.

Welding

Also included in the category of process applications is welding. The largest application for robots at present is in the area of spot welding automobile bodies (see Exhibit 17). Spot welding is normally performed by a point-to-point servo robot holding a welding torch. As in spraying, robots can reduce costs by eliminating costly human

EXHIBIT 16

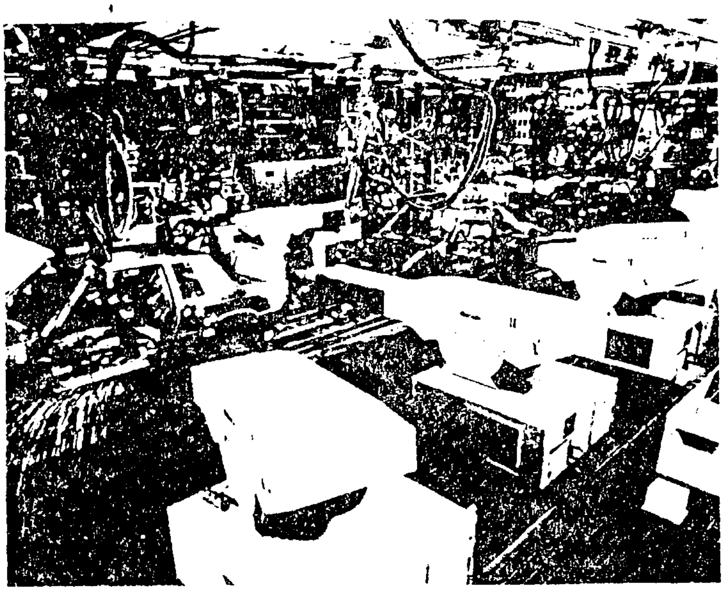
EXAMPLE OF ROBOT SPRAY PAINTING APPLICATION



A DeVILBISS/TRALLFA ROBOT, EQUIPPED WITH AN ELECTROSTATIC SPRAY GUN , APPLIES A LIQUID COATING TO BICYCLE FRAMES (PHOTOGRAPH COURTESY OF THE DeVILBISS COMPANY)

EXHIBIT 17

EXAMPLE OF ROBOT WELDING APPLICATION



UNIMATE ROBOTS PERFORMING WELDING OPERATIONS ON AN AUTOMOBILE ASSEMBLY LINE. (PHOTOGRAPH COURTESY OF UNIMATION, INC.)

labor. Cost reduction is also achieved through the ability of the robot to apply the weld precisely when and where it is needed and thereby reduce waste. In addition, a robot can be supported from the ceiling and can manipulate its end effector to reach points that would be difficult for humans to reach. It can also work in unusual positions without fatigue.

Arc welding can also be performed by robots, although present mechanical-contact seam trackers are limited in application. Several companies are currently working on the development of a good non-contact seam tracking capability for arc welding, which would greatly increase the extent of this application. Robots can perform uniform welding at higher quality and greater productivity than human welders. In addition, arc welding is extremely hazardous and is subject to severe OSHA requirements.

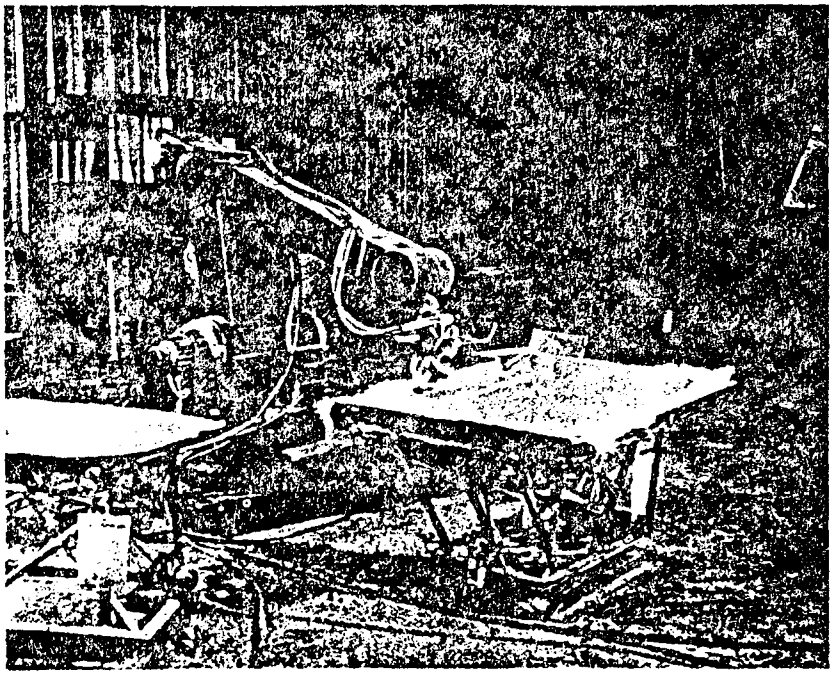
Machining

Robot applications for machining are limited at present partly because of inability to achieve the required accuracy and partly because of the complex tool design required. In a typical machining application, a robot will hold a power spindle and perform drilling, grinding, cutting, or some other operation on a workpiece. The workpiece can be brought to a fixture by a human worker, by another robot, or by a second robot arm on the same robot performing the machining. This second arm capability is becoming more common as microprocessing capabilities continue to increase. Other machining operations possible include forming, finishing, routing, and deburring (see Exhibit 18). For example, the aerospace industry is using robots to drill and route aluminum sheet metal panels.

Drilling represents an example of the difficulty of using robots in machining. Since a robot cannot drill holes to the accuracy required in most applications, a template must be designed for use as

EXHIBIT 18

EXAMPLE OF ROBOT MACHINING APPLICATION



AN ASEA IRb-60 ROBOT ROUTS FIBERGLASS FOR AN AUTO BODY HOOD. (PHOTOGRAPH COURTESY OF ASEA, INC.)

a guide. This is the same procedure that must be followed by human workers. Also, since the position accuracy of currently available robot arms is not high enough to insert a drill without binding, flexible tool holders must be designed to provide slack. An additional complication is provided if sensors are required to determine when the drilling is complete. Sensors may also be needed to determine that a drill bit has broken.

Another type of machining operation may also be viewed as a part handling operation. In this application, the robot moves a workpiece against an exposed stationary tool, such as a buffing wheel or a drill bit, and the machining operation is performed on the workpiece, which is then moved by the robot to another area. The problem with this approach is that the limitations of accuracy also apply, and there also exists a potential hazard by having exposed tools. Machining is likely to remain a somewhat limited application for robots until both improved sensing capabilities and improved positioning accuracy are developed.

Assembly

The area of greatest interest today is in the development of effective, reasonably priced robots for assembly. Presently available robots (point-to-point servo controlled) can be used to a limited extent for simple assembly operations, such as mating two parts together. However, for more complex, precision assembly operations, robots are subject to the same limitations as in the case of machining operations. Improved positioning accuracy and sensing capabilities are required before widespread assembly applications of robots will occur. Not only is sensing required to determine whether parts are correctly positioned before and after assembly, but incoming parts must be inspected to be certain that there are no defects that could harm either the robot or the sub-assembly.

Current applications of robots in assembly operations are feasible only in simple cases. For example, robots can mate parts that simply require pressure to force them together. In the automotive industry, light bulbs are inserted by robots into instrument panels. Automotive assembly lines now use interacting groups of robots to perform simple assembly and machining operations on bodies as they move from one station to another.

However, a slightly more complex task, such as the insertion of a cover that must be screwed into another part, cannot be performed economically by today's robots. The technology is limited, and the cost is too high. Using vision sensing, the cover could be located, and force sensing could be used to prevent excessive stress on the cover. However, the cost of the vision system would be prohibitive, Further, it is likely that a two-armed robot would be required, and the force sensing capability required for screwing insertion has not been developed. In addition, the programming would be extremely complex.

Thus, present robots are capable only of assembly operations that are essentially pick and place operations. Current assembly applications are nothing more than the insertion of one part into another or the mating of two parts that interlock. Major increases in assembly applications will come about only when vision and tactile sensing capabilities are improved and made economical, and when robot arm manipulative capabilities improve.

Inspection

A final area of potential robot application is in the precise measurement of the position of a part for the purpose of checking location, orientation, or dimensions of the part. As in assembly or machining operations, a precise degree of control is required. The types of components used with robots for inspection include television cameras, lasers, photoelectric control modules, fiber optics, and linear diode arrays. Although extremely limited in capabilities at present, there are some robots being used for inspection in industry. For example, the first inspection system in production use is believed to have been installed at General Motor's Chevrolet Division plant in Flint, Michigan in 1979. Manufactured by Auto-Place, the system is used to inspect the valve-cover assemblies of automobile engines to determine if there are leaks and missing parts. Using a programmable controller, the system inspects the valve covers and signals the controller to either accept or reject them. The vision is provided by four General Electric solid-state video imagers.

Another vision system is the Consight system developed by researchers at the General Motors Technical Center in Warren, Michigan. This system can be used to determine the position and orientation of a variety of parts. Another inspection system being tested in production is a sensory feedback system using a microcomputer system for measuring the diameter and position of drilled holes. The ultimate extent to which robots will be used for inspection is directly a function of future developments in vision sensing equipment.

CURRENT ROBOT APPLICATIONS AND EXPERIENCES

The previous discussion concentrated on the types of situations in which robots can offer advantages over manual labor or hard automation. But how well have robots actually accomplished the goals of companies that have used them? To begin, it is useful to review the types of equipment being used and the types of manufacturing environments within which robots are actually being used.

Equipment and Applications

Spot welding of automobile bodies represents the single most important application of robots as of the end of 1981, with as many as one-third of all robots being used in this area. Probably one-half of all robots are being used by the automobile industry. The number of companies using robots is still relatively small, probably in the range of 300-400 firms, with nearly one-third of all robots being employed by just six firms. Metalworking plants are the primary users of robots, although applications in non-metalworking firms, such as plastics, is increasing.

With some 4,000-5,000 robots currently in use in U.S. plants, the extent of robot usage remains small. Since a robot typically displaces about one production worker per shift, this means that robots have thus far only displaced about one out of every 1,500 of the estimated seven million production workers in manufacturing plants who perform the type of work that robots are capable of doing. Currently available robots are capable of performing perhaps 15-20% of those tasks that are suited for robots. With significant improvements in sensing capabilities, this number could increase to as high as 40%. This represents a theoretical potential of from one to three million robots that could someday be used in U.S. manufacturing plants.

As seen in Exhibit 19, the three leading applications for robots account for about 85% of all robot applications. In the 300-400 plants that use one or more robots in their manufacturing operations, robots are used to perform less than 2% of all operations. Robots have experienced their greatest extent of use in applications that are hazardous or unpleasant. Thus, about 8-9% of all welding and spray painting operations in these companies are now performed by robots. In no other application are robots used to perform more than 3% of the operations. This indicates that robots were initially used by companies that wanted to eliminate the need for human labor in

EXHIBIT 19

ROBOT APPLICATIONS IN COMPANIES THAT USE ROBOTS

(300-400 MANUFACTURING PLANTS)

APPLICATION	% OF ROBOTS USED IN APPLICATION	% OF EACH APPLICATION PERFORMED BY ROBOTS
WELDING	40%	8%
MATERIAL HANDLING	25	2
MACHINE LOADING	20	3
SPRAY PAINTING	5	9
ASSEMBLY	3	2
MACHINING	2	1
OTHER	5	<1
	100%	2%

undesirable environments. Increasing pressure from OSHA during the middle of the 1970's, for example, led corporate management to intensify their search for alternatives to human labor in several areas. Robots were found to be ideally suited for these areas. Exhibit 20 shows several examples of actual manufacturing operations for which robots are being used.

The plants in which industrial robots are currently used are generally large, sophisticated operations. In addition to the automobile and aerospace industries, other large equipment manufacturers are current users of robots. Robots are found in both mass production and batch operations, and most companies which use robots also use such sophisticated production tools as numerical control, computer-aided design, and computer aided testing. Over 80% of all companies now using robots began using them less than five years ago (since the beginning of 1977), which shows that the robot industry has only recently shown any significant growth. Nearly half of these robot users began using them during the past two years. Exhibit 21 shows the trend in the number of robots in use since 1969. The large increase during the past five years is expected to continue in 1982, with an increase expected both in the number of plants that use robots and in the number of robots used by each plant. Clearly, the industrial robot has come into its own as a manufacturing tool. Initially used in hazardous or unpleasant working environments, they are now being used in operations in which managers desire improved productivity, reduced operating costs, or improved product quality.

What types of robots are being used? As discussed in Chapter 2, Unimate remains the most popular brand of robot used, although many new models are being introduced regularly. As shown in Exhibit 22, the Unimate 4000 and 2000 are the most often used robots for welding application. Prab and Auto-Place are common names in material handling and machine loading. DeVilbiss/Trallfa is the most popular painting robot. ASEA produces a high quality robot for machining operations, particularly for grinding and deburring applications.

EXHIBIT 20

EXAMPLES OF CURRENT ROBOT APPLICATIONS

MANUFACTURING OPERATION	SAMPLE ROBOT APPLICATIONS
MATERIAL HANDLING	• Moving parts from warehouse to machines • Depalletizing wheel spindles into conveyors • Transporting explosive devices • Packaging toaster ovens • Stacking engine parts • Transfer of auto parts from machine to overhead conveyor • Transfer of turbine parts from one conveyor to another • Loading transmission cases from roller conveyor to monorail • Transfer of finished auto engines from assembly to hot test • Processing of thermometers • Bottle loading • Transfer of glass from rack to cutting line • Core handling • Shell making
MACHINE LOADING/UNLOADING	• Loading auto parts for grinding • Loading auto components into test machines • Loading gears onto CNC lathes • Orienting/loading transmission parts onto transfer machines • Loading hot form presses • Loading transmission ring gears onto vertical lathes • Loading of electron beam welder • Loading cylinder heads onto transfer machines • Loading a punch press • Loading die cast machine
SPRAY PAINTING	• Painting of aircraft parts on automated line • Painting of truck bed • Painting of underside of agricultural equipment • Application of prime coat to truck cabs • Application of thermal material to rockets • Painting of appliance components
WELDING	• Spot welding of auto bodies • Welding front end loader buckets • Arc welding hinge assemblies on agricultural equipment • Braze alloying of aircraft seams • Arc welding of tractor front weight supports • Arc welding of auto axles
MACHINING	• Drilling aluminum panels on aircraft • Metal flash removal from castings • Sanding missile wings
ASSEMBLY	• Assembly of aircraft parts (used with auto-rivet equipment) • Riveting small assemblies • Drilling and fastening metal panels • Assembling appliance switches • Inserting and fastening screws
OTHER	• Application of two-part urethane gasket to auto part • Application of adhesive • Induction hardening • Inspecting dimensions on parts • Inspection of hole diameter and wall thickness

EXHIBIT 21

NUMBER OF ROBOTS IN USE IN U.S. MANUFACTURING PLANTS

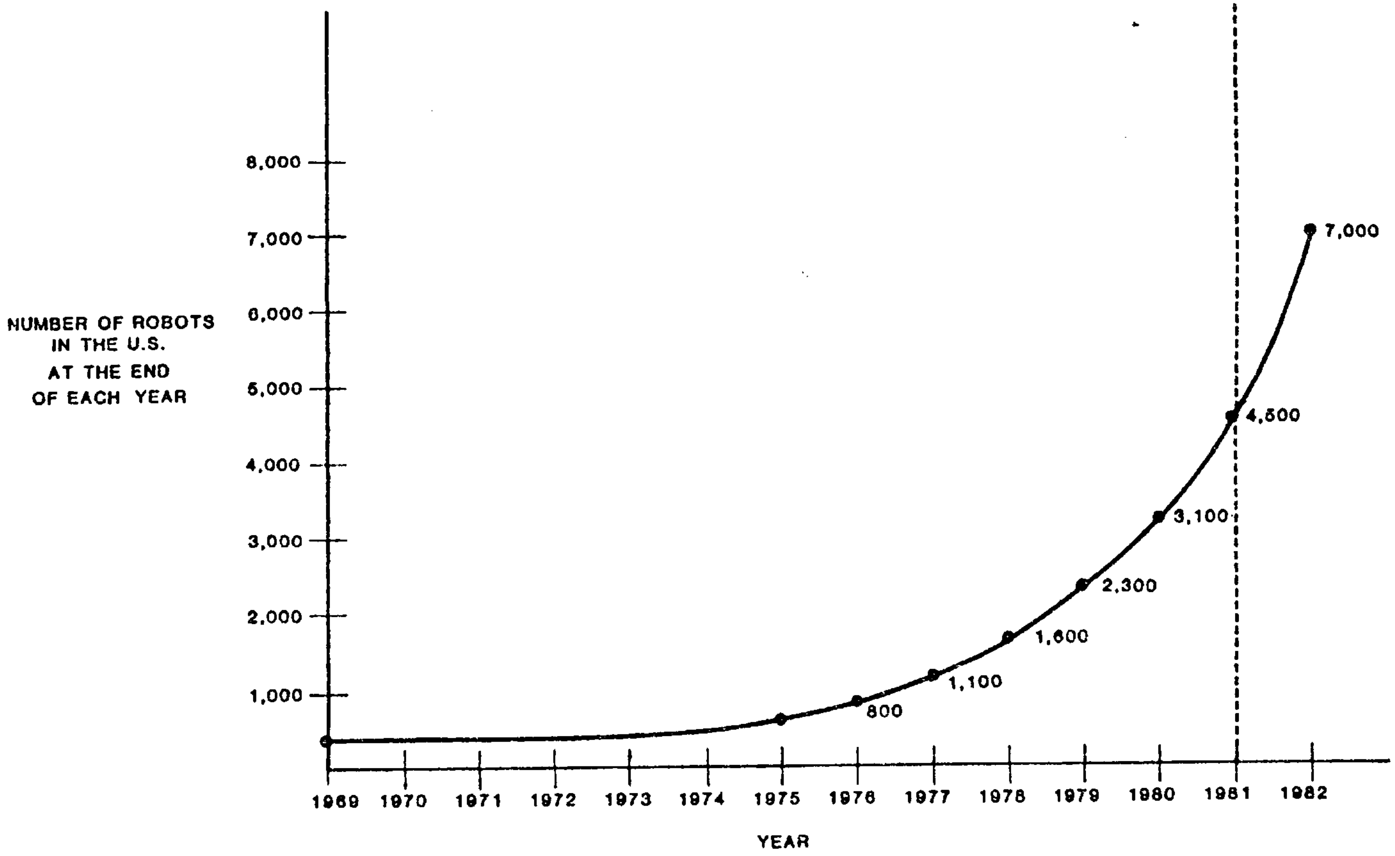


EXHIBIT 22

MOST POPULAR ROBOT BRANDS/MODELS CURRENTLY USED, BY APPLICATION

APPLICATION	BRAND/MODEL
WELDING	UNIMATE 4000 UNIMATE 2000 CINCINNATI MILACRON T3 CINCINNATI MILACRON HT3 ASEA IRb-6
MATERIAL HANDLING	UNIMATE 2000 CINCINNATI MILACRON T3 PRAB VERSATRAN E AUTO-PLACE 10
MACHINE LOADING	UNIMATE 2000 CINCINNATI MILACRON T3 PRAB 4200/5800
SPRAY PAINTING	DE VILBISS /TRALLFA BINKS NORDSON CYBOTECH
ASSEMBLY	CINCINNATI MILACRON T3 SEIKO UNIMATE PUMA
MACHINING	ASEA IRb-6 CINCINNATI MILACRON T3

Assembly robots are limited in capability, and generally are used for small parts assembly (under 5 pounds in weight), as in the case of the Seiko or the Unimate Puma.

Most robots being used have no external sensing capability, and those that do typically use some type of a simple limit switch, such as in the case of welding or simple assembly. Nearly all robots are manually programmed, using a teaching control box or walkthrough programming. Fewer than 10% of these robots can be programmed using an off-line computer.

User Experiences

Experiences with industrial robots during the early 1970's were often unfavorable. Many companies, eager to eliminate the need for human labor in hazardous or monotonous jobs, installed robots. However, some robots were either removed or their use was curtailed as companies found that the capabilities of the robots were severely limited. Poor positioning accuracy, limited manipulative capabilities of the grippers, and unreliability were a few of the early complaints of users. Capabilities of today's robots have improved substantially, primarily in the areas of accuracy, gripper dexterity, and control. As a result, robots for the first time appear to be capable of fulfilling their original promise.

But how well are today's robots actually performing? It has been over five years since the use of robots in manufacturing plants began to increase dramatically. On the average, companies which use robots have had about two or three years of experience, which is an adequate amount of time to begin to evaluate the performance of these robots. Since it appears that robotics technology has now advanced to a stage where future increases in use are likely to continue at a rapid pace, this is an excellent point at which to evaluate whether or not there are any gaps between user expectations and actual robot performance.

Reasons for Purchase

As discussed earlier, a robot can be purchased for a variety of reasons, depending on the application for which it is intended. In practice, companies that use robots have purchased them primarily for economic reasons, as seen in Exhibit 23. Robots are most often purchased to achieve a reduction in direct labor costs, followed by a desire to achieve productivity. In the case of spray painting, robots are purchased primarily to eliminate the need for human labor in an environment that is unpleasant or even hazardous. A second important purchase reason is that robots are expected to improve the quality of the painting job. Many users have also found that robots can perform many unpleasant material handling tasks which human workers are reluctant to perform, such as the transport of objects that are heavy, hot, cold, or chemically hazardous. Productivity is the primary concern of users in such applications as machine loading and assembly, in which the rate of production may be limited when human workers are used.

Overall Evaluation

In general, users are satisfied with the performance of their robots. In a recent survey, 85% of all users stated that their robots either met or exceeded their original expectations of performance. Five years ago, this number would have been considerably lower. Those who are not satisfied with the performance of their robots in most cases set their expectations too high. Although robotics technology has improved considerably in recent years, it is essential that the limitations of robots be taken into account when deciding to use them. Companies not satisfied with robots generally cite a high payback period as a problem. This can normally be traced back to an

EXHIBIT 23

REASONS FOR USING ROBOTS, BY APPLICATION

(RANKED IN ORDER OF IMPORTANCE:
1 = MOST IMPORTANT, 4 = LEAST IMPORTANT)

	REDUCTION IN DIRECT LABOR COSTS	INCREASE IN PRODUCTIVITY	HAZARDOUS/ UNPLEASANT WORK	IMPROVED PRODUCT QUALITY
WELDING	1	2	4	3
MATERIAL HANDLING	1	3	2	4
MACHINE LOADING	2	1	3	4
SPRAY PAINTING	3	4	1	2
ASSEMBLY	2	1	4	3
MACHINING	1	2	4	3
INSPECTION	3	2	4	1
ALL OPERATIONS	1	2	3	4

application in which robots are not being used for more than one shift. Robots are generally no faster than humans, and so if the goal is to reduce costs or increase productivity, it is important that robots be used in a two or three shift operation.

Direct labor employees also appear to be satisfied with the implementation of robots in their plants. Most direct labor personnel, once they have become educated about the ways in which robots can be ,used, tend to view them as a means to eliminate unpleasant tasks. In addition, many direct labor personnel see robots as a way for them to upgrade their skills and advance to higher level jobs. Workers generally view robots as a threat only before they fully understand that robots have been used to displace rather than replace human workers.

Top management in most companies has also been generally satisfied with the performance of robots. Top management personnel, concerned with manufacturing costs and productivity, view robots as an effective means to improve the economic performance of their manufacturing operations. In many companies, corporate management also feels that the quality of some products has improved through the use of robots.

Economics of Use

The primary measurement of economic performance of robots being used by robot manufacturers and by users is the payback period. In its simplest terms, the payback period represents the number of years required for the cumulative cost savings from using a robot to equal the initial investment in the robot. Generally, robot manufacturers claim payback periods of one to two years. Payback periods of robots in use range from a low of 0.5 years up to as high as five years, depending on the application for which the robot is being used and the amount of time during which it is used. On the average, companies that have used robots report payback periods of about two years. There is a direct correlation between the payback period and the user's overall evaluation of the robot's performance, which indicates the importance of economic justification to most users. Although non-economic factors, such as improved worker morale, are often cited as justifications for using robots, users ultimately translate the impacts of these factors into financial numbers.

Although robots should ideally be used in three shift operations to capitalize upon their ability to work continuously without fatigue, currently used robots are divided equally among one, two, or three shift operations. Robots tend to be used in three shift operations for machine loading and some welding operations. Two shift robots are used for welding, painting, and material handling operations. One shift robots are found in machining, assembly, material handling, and painting. Generally, the more established robot applications are those in which robots are used for two or three shifts, while one shift robots are used for more complex applications in which robot capabilities have not been firmly established.

The actual payback period that can be expected after installing a robot is a function of the total cost of the robot, the nature of the application, and the number of shifts or production volume of the operations. A robot costing $200,000 or more (total installed cost) will generally have a payback period of at least three or four years. A two year payback period is typical for a robot in the $100,000-$150,000 range. For robots costing $50,000-$100,000, a payback period of slightly more than one year can be expected. Robots used for machine loading and unloading, which are often operated on a three shift basis, can be expected to have fairly short payback periods, generally in the one to two year range. Welding robots, which are relatively costly and are typically used on a two shift basis, have relatively long payback periods, in the range of two, three, or four years.

Although robot prices vary widely, a sample of some of the more commonly used sophisticated robots in typical manufacturing operations shows that an average price for an installed robot is about $115,000 (see Exhibit 24). This includes the basic robot, all accessories (such as optional equipment, special tools, grippers, and maintenance and test equipment), and installation costs (site preparation, work rearrangement, utility connections, interfaces, etc.). The cost of the basic robot (base, manipulator, controller, and power supply) is about 56%, or $64,000, of this total. Accessories represent 28%, or $33,000 and installation is an additional $18,000 (16% of the total cost).

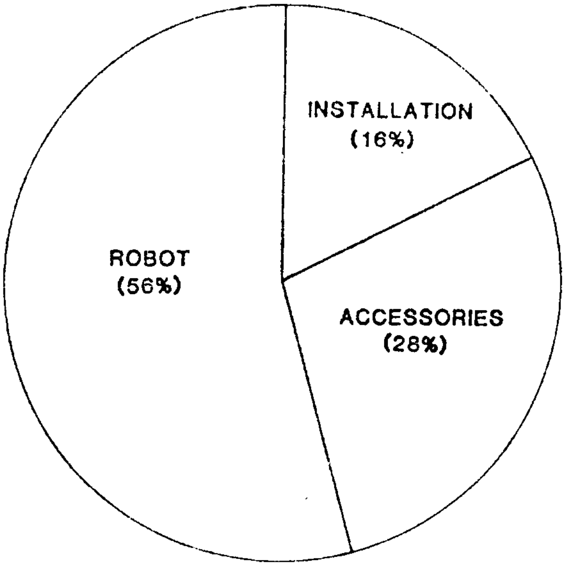
These numbers vary by robot application. The least costly robots are being used in material handling applications ($75,000 average total cost), where a number of less sophisticated, non-servo robots are found. The most expensive robots are those used for welding applications, such as the Unimate, Cincinnati Milacron, or ASEA robots, which currently cost an average of about $160,000. In general, note that the more expensive robots tend to require greater expenses in the areas of accessories and installation than the less expensive robots. It is important to bear in mind that the basic robot represents only slightly more than half of the total cost of the installation. Furthermore, this does not include the planning and applications engineering work that is normally required before a robot is purchased. This planning cost can add tens of thousands of dollars to the total cost of a robot installation.

Robot Problem Areas

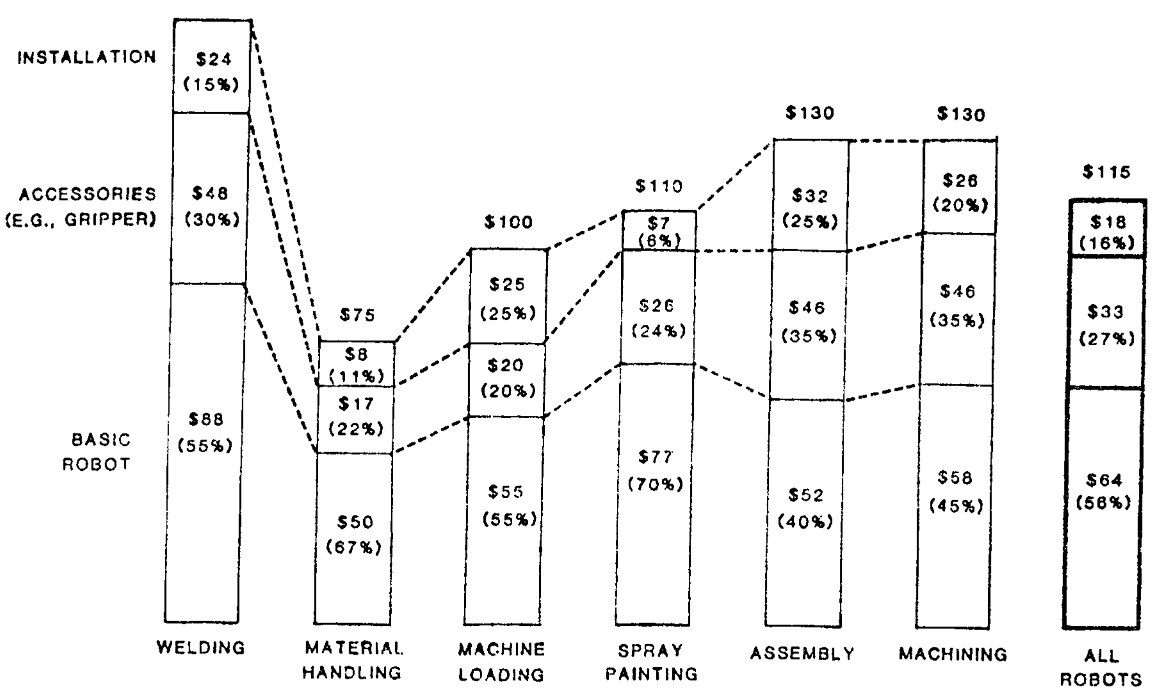
As discussed earlier, the impact of robots on the U.S. economy as a whole is insignificant at the present time. The several thousand robots now in use in manufacturing plants must be increased to several hundred thousand or even several million before a truly major impact will be felt on the economy. There are probably from one to three

TYPICAL ROBOT SYSTEM COST BREAKDOWN

EXHIBIT 24



ALL ROBOTS



BY APPLICATION ($000)

million potential manufacturing operations in the U.S. alone which could be performed by robots. Adding to this the number of potential applications in Japan, Europe, and other areas leads to a worldwide number of tens of millions of potential robot installations in manufacturing operations.

Before this can be achieved, however, certain improvements in robot capabilities will be required. The recent surge of interest in robotics came about as improvements in positioning accuracy, reliability, load capacity, and gripper design were achieved. Today's robots can achieve accuracies on the order of ±.010 inches, can lift weights of hundreds or even thousands of pounds, and can perform sequences of motions requiring hundreds of steps. However, today's robots cannot perform complex assembly or machining operations requiring high degrees of accuracy and sensing capabilities. Certain improvements in the technology will be required before usage in these areas becomes widespread. In addition, there are some operations in which robots are unlikely to be used, at least in the foreseeable future, because the nature of the technology does not match the requirements of the task. For example, certain complex assembly operations in job shop environments will continue to be performed by humans, not only because of the sophistication of the robot required, but also because the high robot programming cost for a one time operation would be prohibitive. Similarly, tasks requiring a high degree of judgment and decision making capability are likely to continue to be performed by humans.

What are the limitations of today's robots? The best source of information on problem areas is the group of companies that have had actual experience in using robots. As seen in Exhibit 25, there are presently three major areas in which robot users feel that significant improvements in robots are required:

- <u>Low cost, effective position and shape sensing</u> - The greatest limitation of robots being used today is the lack of an

CURRENT ROBOT PROBLEM AREAS OR NEEDED IMPROVEMENTS

(Specified by users in each application)

KEY:
● = MAJOR PROBLEM/NEED
◑ = MODERATE PROBLEM/NEED
○ = MINOR/NO PROBLEM

	PROBLEM AREA/ IMPROVEMENT NEEDED	WELDING	MATERIAL HANDLING	MACHINE LOADING	SPRAY PAINTING	ASSEMBLY	MACHINING	INSPECTION	ALL APPLICATIONS
ROBOT CAPABILITIES	1. LOW COST, EFFECTIVE VISION SENSING	●	●	●	◑	●	◑	●	●
	2. EASIER, STANDARDIZED PROGRAMMING	◑	◑	◑	●	●	●	●	●
	3. IMPROVED GRIPPER DEXTERITY	○	●	◑	○	●	◑	○	◑
	4. GREATER FLEXIBILITY-NUMBER OF APPLICATIONS	○	●	◑	○	◑	○	○	◑
	5. LOW COST, EFFECTIVE FORCE SENSING	○	○	○	○	◑	●	◑	○
	6. LIGHTER, SMALLER ROBOTS	○	◑	○	○	◑	○	○	○
	7. IMPROVED CONTROL SYSTEMS	◑	○	○	○	◑	◑	◑	○
ROBOT PERFORMANCE	1. GREATER SPEED	○	●	●	○	●	○	○	◑
	2. IMPROVED POSITIONING ACCURACY (WITHIN ±.005")	●	○	◑	○	●	●	●	◑
	3. IMPROVED REPEATABILITY	●	○	◑	○	●	●	●	◑
	4. IMPROVED RELIABILITY	◑	○	○	◑	◑	◑	○	◑
OTHER NEEDS	1. REDUCED ROBOT COST	●	◑	●	●	●	●	●	●
	2. IMPROVED ABILITY TO INTERFACE WITH EXISTING EQUIPMENT	◑	○	◑	○	◑	○	◑	◑
	3. IMPROVED SAFETY	◑	○	○	◑	○	○	○	○
	4. TURNKEY SYSTEMS	◑	◑	◑	◑	○	○	○	○

EXHIBIT 25

effective, reasonably priced sensing capability for determining the location, orientation, or shape of an object. Although several technologically feasible sensors are available, the price tends to make them economically unfeasible. In addition, the software required for analyzing data received from sensors and translating it into a form usable by the robot is not well developed. The ability of robot controllers to interact in real time with sensors is limited. Both the software interface capability and the sensing technology must be improved to enable robots to recognize patterns, determine the location and orientation of objects, avoid collisions, detect flaws, and detect the presence of materials. Although optical sensors are most often associated with this type of sensing, other types of sensors, such as acoustic, electromagnetic, and X-ray, are also employed.

- Easier, standardized programming - Many users have experienced difficulty in programming their robots. They have found that the time required to program the robot is longer than originally expected, that programming the robot is more complex than expected, that programming languages are not standardized, that off-line programming is difficult to accomplish, and that it is difficult to program a robot for small lot production runs. Users need to have available a range of standardized programming languages at each level of robot application, including languages that allow better interfacing with computer-aided manufacturing (CAM) equipment.

- Reduced robot equipment cost - Robot prices have remained fairly constant in recent years, in part because the price of the robot electronics has declined, allowing greater control capabilities at the same price level. However, the average installed cost of a typical robot is considered to be too high by most users, particularly in light of the extremely short payback periods that are required in today's economy to justify investments in capital equipment. The installed price of a robot can decrease in the future if high sales volumes for robots are achieved. Another way that prices can be reduced is the use of a single controller to control several robots (unlike today, in which one controller per robot is required). This assumes that major improvements in controller technology will occur.

In addition to these fundamental areas of concern by robot users, there are several other problems that users feel must be overcome in order for robots to become widely accepted. The relative importance of these problems is in many cases a function of the particular application for which the robot is being used, as seen in Exhibit 25. In general, robots used for spray painting applications appear to have the fewest problems, while assembly robots need the greatest number of improvements. In the area of robot capabilities (i.e., what the robot is capable of doing), problems that are of a moderate or minor nature include the following:

- Improved gripper dexterity - Many users are concerned that the basic open and shut operation of most currently available grippers is not adequate for some of the complex movements required in certain operations, especially in complex assembly and material handling operations. The problem is not so much in designing a multiple jointed gripper as in designing the complex control algorithms necessary to control the movements of the gripper.

- Greater flexibility - In material handling operations especially, some users are concerned that currently available robots are not adequately flexible to enable them to perform a variety of different tasks. This is a concern in any manufacturing environment in which many different types of jobs are performed.

- Low cost, effective force sensing - Of particular concern to users of robots for machining and assembly operations is the development of an effective sensing capability for determining the position of an object through the measurement of contact forces. In drilling, for example, a force sensor would tell a robot controller that the drilling operation is complete when it detects the pressure of an obstruction to prevent further movement.

- Lighter, smaller robots - Robots are typically very large and heavy, and can lift weights equal to only about 10% of their own weight. Many users want smaller robots with greater relative load capacity, for example, in the material handling area. In assembly operations, smaller robots are required to handle delicate or intricate parts. By combining advanced servo capabilities with developments in lightweight materials, the prospects for lighter and smaller robots in the future are quite good.

- Improved control systems - Several areas of improvements are required in robot control systems. Controllers need to be much more sophisticated in their ability to interact between robots and sensors and cause changes in the movements of the robots based upon feedback received from sensors. Sensory data must be made available and transformed into control instructions for robots within just a few milliseconds. In addition, the ability of controllers must be improved to enable them to receive much more complex sensory data than presently possible. They must be capable of interacting with sensors on a "real time basis." Although users do not perceive this limitation of robots to be a truly significant problem (probably because of lack of knowledge about the function of controllers), the impact of improvements in this area, combined with improvements in sensing capabilities, is likely to be major.

In the area of robot performance (i.e., how well they perform their jobs), several areas of improvements are also felt by users to be needed:

- Greater speed - Although end-of-arm speeds of up to 60 inches per second are now possible, robots are generally unable to complete most manufacturing cycles at rates faster than humans. In some operations, such as arc welding or spray painting, this is not a problem, since the robot speed is limited by the constraints of material application. In other operations, such as assembly, certain machine loading operations, and certain material handling operations, the cycle time can be limited by the speed of the robot rather than the dynamics of the operation. Many users in these areas would like to have greater robot speeds available. To accomplish this, servo systems must be improved to better accommodate the rapid changes in inertial characteristics of the robot manipulator as velocities and accelerations change during the cycle.

- Improved positioning accuracy - Robots can achieve positioning accuracies on the order of ±.010, ±.020, or ±.030 inches. However, many assembly and machining operations require accuracies of less than ±.005 inches. The only way to assure a high degree of positioning accuracy with current robots is to manually teach them. In assembly or machining operations requiring a high degree of accuracy, off-line programming cannot be used. This means that robots will not be economical in batch or job shop assembly or machining operations because of the high programming cost incurred in manual teaching. The only way to improve accuracy is through some form of robot calibration technique, or through greater precision in the manufacture of robots.

- Improved repeatability - Similarly, these users are concerned about the ability of the robot to return to the same position each time. The same improvements as above would be required, although in this case, the initial programming approach is of less concern.

- Improved reliability - Robot manufacturers claim average robot uptimes of 98%. Robot users report actual average uptimes of 96%, which is very good. However, robot productivity depends on the amount of time that it is in service, and so some users would like to see improvements in reliability. The specific areas of concern include component part failures, the high level of skill required for maintenance, and the excessive wear of components that some users have experienced in abrasive environments.

Several other areas of concern have also been identified by robot users. The high cost of robot equipment has already been discussed. Other improvements needed include:

- Improved ability to interface with existing equipment - Many companies have found that it is difficult to effectively integrate robots with machine tools, computers, sensors, and other manufacturing equipment. With the trend toward the increasing use of group technology in which several pieces of equipment act as an integrated system, there is a need for standardized interfaces and programming packages so that all components of the system can communicate with each other. This will be especially important as sensors are increasingly used as feedback devices for robots to adjust to changes in the environment.

- Improved safety - Robot work envelopes can be fairly large, and manipulator motions can be fast, by human standards. Some users are concerned that greater safety precautions may be necessary to prevent humans or machinery from entering into the robot work envelope. For example, improved interlock mechanisms on robot arms may be required to prevent the motion of the arms into prohibited areas. Sensing devices may also play a role in preventing collisions between robot arms and humans or machines.

- Turnkey systems - Some robot users, concerned about the high cost, time, and complexity of implementing a robot system, would like to see more manufacturers provide complete turnkey robot installations. This would cover the entire process, from initial planning through installation and initial operations.

While robotics technology has advanced greatly during the past several years, it is clear that many improvements are still required in order for robots to achieve their full potential. With currently available technology, robots can be used to perform certain tasks in all of the major categories of manufacturing operations. However, robots will not be used to the extent of their full potential in each area until the problems shown for each application in Exhibit 25 are overcome. Complex operations such as assembly, machining, or inspection, require that a greater number of improvements in robotics technology be achieved than for simpler operations, such as spray painting.

When considering the use of a robot in a specific application, as will be discussed in Chapter 5, it is necessary to thoroughly study the nature of the task to be performed, the production volume, and the speed of the production run, and then compare these requirements with the capabilities of specific robots. The robot selection decision must be made on a case by case basis. It is important to bear in mind, however, that there are suitable applications for currently available robots in most manufacturing operations. Only in a few selected areas, such as complex assembly operations, is it necessary to wait for improvements in robotics technology before deciding to purchase a robot. In most cases, today's robots can do the job.

FUTURE DEVELOPMENTS

Today the robot industry is booming and it is expected that rapid growth will continue through the 1980's and 1990's. Even with no further improvements in robot capabilities, there would likely be a major increase in robot usage in many manufacturing operations since existing robots are not yet being used to their full potential. Material handling, machine loading, and spot welding are a few of the areas in which robots are being used in only a small percentage of operations for which they are suitable.

Although growth in the use of robots throughout the next decades seems to be assured, there are several problems that could prevent the application of robots from being even more widespread. If the problems discussed in the last chapter are not resolved, the industry could reach a saturation point within another decade. However, the industry is not standing still. Robot manufacturers are spending considerable sums of money in R&D efforts. Robotics research is also being conducted by several organizations, including universities, non-profit laboratories, private industry and government laboratories.

The type of developmental work being performed by these organizations is generally aimed at resolving these problems. Research organizations are concentrating primarily on developing improved sensing and control capabilities, while robot manufacturers are emphasizing several mechanical improvements and cost reductions along with sensing, control, and programming developments. Before discussing areas of research and development efforts in more detail, it is helpful to review the major current problems with robots as perceived by each of the participants in the industry: the manufacturers, the researchers, and the users.

PROBLEMS AND DEVELOPMENTAL NEEDS

As seen in Exhibit 26, the problems encountered by robot users are also seen as problems by robot manufacturers, research organizations, and companies planning to use robots, although the relative importance of each may be viewed differently.

At the top of the list of problem areas for all segments, and the subject of more research than any other area, is the need for an effective, low cost vision system. Rudimentary vision systems exist today that sell for around $20,000. Most of these robot vision systems allow the robot to "see" in two dimensions as long as the objects contrast sharply with their background and do not touch or overlap each other. These commercial two-dimensional vision systems are unable to differentiate among objects which have similar silhouettes, but have differing low-contrasting surface finishes and characteristics. However several vision systems have been developed and installed in industrial applications. These are mainly simple pattern recognition applications where the vision system was "taught" the dimensions and shape of the part beforehand. A comparison is then performed by the computer for recognition purposes and a decision is made based upon that comparison.

Because of the limitations of two-dimensional vision systems, most research organizations are now experimenting with three-dimensional vision systems. However, because of the increase in complexity of three-dimensional vision systems, it is unlikely that an effective, low cost general purpose vision system will be developed before 1990. The lack of a three-dimensional vision system will not have an adverse effect on the growth rate of the robot industry during the 1980's. Most robot manufacturers feel that even with today's vision systems, there are thousands of economical applications in which robots with vision could be effectively used. A vision system which will allow a robot to recognize, grasp and orient a part picked

EXHIBIT 26

CURRENT ROBOT PROBLEM AREAS OR NEEDED IMPROVEMENTS, AS VIEWED BY ROBOT MANUFACTURERS, RESEARCHERS, AND USERS

KEY:
● = MAJOR PROBLEM/NEED
◑ = MODERATE PROBLEM/NEED
○ = MINOR/NO PROBLEM

	PROBLEM AREA/ IMPROVEMENT NEEDED	ROBOT MANUFACTURERS	ROBOT RESEARCHERS	COMPANIES PLANNING TO USE ROBOTS	COMPANIES THAT USE ROBOTS
ROBOT CAPABILITIES	1. LOW COST, EFFECTIVE VISION SENSING	●	●	●	●
	2. EASIER, STANDARDIZED PROGRAMMING	●	●	◑	●
	3. IMPROVED GRIPPER DEXTERITY	●	○	◑	◑
	4. GREATER FLEXIBILITY-NUMBER OF APPLICATIONS	○	◑	◑	◑
	5. LOW COST, EFFECTIVE FORCE SENSING	○	◑	◑	○
	6. LIGHTER, SMALLER ROBOTS	◑	○	○	○
	7. IMPROVED CONTROL SYSTEMS	○	◑	○	○
ROBOT PERFORMANCE	1. GREATER SPEED	◑	○	○	◑
	2. IMPROVED POSITIONING ACCURACY (WITHIN±.005")	◑	◑	○	◑
	3. IMPROVED REPEATABILITY	◑	◑	○	◑
	4. IMPROVED RELIABILITY	○	○	○	◑
OTHER NEEDS	1. REDUCED ROBOT COST	●	◑	●	●
	2. IMPROVED ABILITY TO INTERFACE WITH EXISTING EQUIPMENT	◑	○	○	◑
	3. IMPROVED SAFETY	○	◑	○	○
	4. TURNKEY SYSTEMS	◑	○	◑	○

from a moving conveyor system would be viewed as a major breakthrough by robot users. An effective vision system of this type may be available by 1985 but will probably sell for $25-30,000.

A second major problem area in robot capabilities is the lack of a standard programming language for robots. Presently there are more than a dozen different ways to program robots. Some companies have air logic controllers where air hoses are moved from one fitting to another for reprogramming; others have mechanical drums with plastic inserts which are moved to different positions for programming; some have only mechanical stops and control valves for programming, and many now are using microprocessors for programming. Computers have introduced many complexities into the job of programming a robot for the untrained person. Some robots are programmed by software languages such as PASCAL, others use manufacturer developed languages such as VAL, many use a walkthrough method, others use a teach pendant, and still others use a combination of many of the above. An operator can be an expert in operating one robot system and totally unable to operate another similar robot system, simply because of differences in programming.

Although all segments of the robot industry are in agreement that there is a need for a standard robot programming language, it is doubtful that a truly major breakthrough will occur in the near future. However, some improvements are likely. A few organizations are considering the feasibility of expanding the use of APT (Automatic Programming Tool), which is widely used for programming NC machines, to robots. This would be the first step in developing a standard language for robots and would make hardware and software interfacing between automated machines significantly easier.

The problem of machines interfacing and communicating among each other has always caused enormous software problems. These interfaces, both hardware and software, need to be standardized so that many robots, machine tools, material handling equipment, sensors, and large control computers can be connected together in integrated systems. This is another area where standardization will be difficult to achieve. There appears to be very little work being performed by robot researchers in this area. Most robots manufactured today have only limited communication capability, typically consisting of an on/off sensing capability. However, this appears to satisfy the majority of the needs of current robot users, since truly integrated systems are not yet being widely employed. In the future, when more integrated systems come on line, sophisticated communication channels between computers, robots, sensors, and other machines will be a must.

Another area where little research is being conducted is in gripper design. There are only a limited number of research organizations performing work in this area. The difficulty in developing a general purpose gripper is in trying to duplicate the human hand. Today's typical grippers are of the parallel-jaw type with only one degree of freedom, open and shut. A gripper similar to the human hand would require several fingers, and each would need 3-4 degrees of freedom. The mechanical design of such a device is possible, but the control algorithms are of such complexity that no solutions have been developed. The robot manufacturers view improved gripper dexterity as a major problem. This is because nearly every robot sold has a special purpose gripper designed either by the robot manufacturer or user, regardless of the application. This special purpose tooling tends to be expensive and can be the deciding factor in determining whether or not to purchase a robot. The user who already has robots installed considers improved gripper dexterity to be a moderate problem. This is because once a robot has been chosen for a particular application, it is not often changed to the extent that retooling is required.

Several problem areas have been identified in the area of robot performance. One of the first problems which needs to be corrected is inadequate positioning accuracy. In some cases, positioning accuracy can have a range of error as high as several tenths of an inch. This poor positioning accuracy creates major problems when programming with a CRT (Cathode Ray Tube). It means that each robot must be programmed by leading it through the desired path, a time consuming job. Also, leading the robot through its path makes it almost impossible to edit a program other than by redoing the entire path. Until this problem is solved, small lot batch assembly will not be economical using robots that are programmed via CRT's.

Another problem identified by both robot manufacturers and users is the speed at which robots move through an operating cycle. Typical robots of today do not work any faster than human workers. This is why most robot applications to date have been in those jobs which are undesirable to humans. If robots are to perform jobs requiring cycle times of less than 3-5 seconds, then faster end-of-arm speeds will be required.

The final problem area in robot performance identified by the users as a moderate problem with today's robots is reliability. Although users claim that their experiences with the reliability of robots has been good, many feel that there is a need for more reliable systems with better MTBF (mean time before failure). Several manufacturers list their systems with a 98% uptime and an MTBF of 2000-4000 hours. As the complexity of robot systems increases in the near future, it will become even more important for robot reliability to improve.

Today's robots need improvement in two other important areas. First, robots are expensive. Both users and manufacturers agree that the cost of robots must come down in order for more widespread application to be developed. It is difficult to justify a $100,000-200,000 robotic system except in certain types of manufacturing environments. However, a $10,000-20,000 robot system would have a tremendous number of applications. Finally, an area of concern to both potential users and robot manufacturers is the need for more turnkey robot systems. Many small companies have applications for robots but not the capability to install, check-out, maintain and integrate them with other industrial equipment.

RESEARCH ORGANIZATIONS

There are four general categories of organizations in which robotics research and development activities in the U.S. are being conducted:

- University
- Non-profit
- Private Industry
- Government

A sample of some current research programs being conducted by these organizations is shown in Exhibit 27.

University Research

The list of universities conducting research in robotics is growing as fast as the list of new robot manufacturers. However, there are a few which have been performing significant research for several years. Stanford University has been one of the pioneers in robotic research since the mid-1960's. Stanford's research is directed toward the development of three robot capabilities:

EXHIBIT 27

EXAMPLES OF CURRENT RESEARCH EFFORTS

ROBOT CAPABILITY	RESEARCH PROGRAMS
SENSING	• COMPUTER ANALYSIS OF IMAGES • 3D, STEREO EDGE, TEXTILE VISION • TACTILE SENSING • FORCE SENSING • CAMERA SYSTEMS • PATTERN RECOGNITION • INTERFACE DEVELOPMENT • MULTIPLE LIGHT SOURCES AND MOTION TO ANALYZE SCENES • RADAR, SONAR, AND INFRARED SENSING • TV/DIGITAL INTERFACE • COLLISION AVOIDANCE
GRIPPER DESIGN	• MULTI-FINGERED FLEXIBLE GRIPPER • FORCE SENSING PARALLEL JAW GRIPPERS • 3-FINGERED FLEXIBLE GRIPPER • 2-FINGERED MULTIPLE GRIPPER WITH SENSING
ROBOT CONTROL	• ADAPTIVE, FLEXIBLE LINKAGES • CARTESIAN FORCE CONTROL TRACKING • COOPERATING MANIPULATORS • SELF LEARNING CONTROL • INTEGRATION WITH CNC • CONTROL SYSTEM FOR ROBOT SAFETY • INTEGRATIVE FEEDBACK LOW-LEVEL COMPUTER CONTROL • DYNAMICS, KINETICS, INERTIA
PROGRAMMING	• HIGHER LEVEL LANGUAGE DEVELOPMENT • GEOMETRIC MODELLING • REAL TIME INTERACTIONS BETWEEN SENSORS AND CONTROL SYSTEMS • OFF-LINE PROGRAMMING • PROGRAMMING LANGUAGES FOR NON-TECHNICAL INDIVIDUALS • SOFTWARE FOR VISION SYSTEM
ROBOT ARM DESIGN	• HIGH PERFORMANCE ARM • GEARING, STEPPER vs DC MOTOR • GREATER PRECISION
OTHER	• COMPLIANCE • ARTIFICIAL INTELLIGENCE (SPEECH, VISION) • ROBOT MOBILITY • IMPACT OF ROBOT INTRODUCTION ON EMPLOYEES • MAN-MACHINE INTERFACE

1. Force sensing and force sensory/motor control.

2. Very high level language for robots including geometric reasoning, geometric and mechanical models, planning, and libraries for assembly.

3. Three-dimensional inspection and vision with geometric models and geometric reasoning.

Significant contributions by Stanford University include the development of one of the most advanced robot programming languages available today called AL, for Arm Language. Stanford has also developed a simulation language which allows users to debug robot manipulator programs. This program, called SIMULATOR, uses computer graphics and enables off-line programming of tasks for robots and provide the user with a "try before you buy" option. SIMULATOR interfaces with several modeling languages (ACRONYM, PADL) and several robot programming languages (AL, APT, VAL). Work is continuing on a vision system for inspection and control systems for robots. Stanford is presently developing ACRONYM, which is a vision system for inspection and picking parts from bins. A joint program between JPL and Stanford is producing a three finger hand with nine degrees of freedom. Stanford has also designed a hand which consists of independently controlled finger modules and force sensing finger pads.

Massachusetts Institute of Technology (MIT) has been conducting research in robots as long as Stanford. MIT has an annual budget for robotics research of about $2,000,000 and research efforts are in the area of vision and force sensing, gripper design, and higher level language development. MIT has developed a touch sensor similar to an "artificial skin" for use on a robot finger. This sensor is about the size of a human finger tip and can discriminate among several similar objects. The "skin" consists of sheets of silicone rubber impregnated with graphite which makes contact with a printed circuit board when pressure is applied.

MIT's Artificial Intelligence Laboratory has been conducting research in robot vision systems for several years. Present research is concentrating on the development of a three-dimensional vision system based upon binocular type vision for depth perception. MIT is also active in the development of programming languages, learning capabilities and geometric modeling.

Carnegie-Mellon University's Robot Institute (Pittsburgh) is one of the newer universities now conducting research in robotics. The major research efforts have been in the areas of vision, arm and hand design and mobility. A unique depth sensor has been developed which uses a circle of light-emitting diodes that allows the robot vision system to scan an object to determine its shape and dimensions.

CMU is developing a lightweight, all electric arm which will eliminate the problems of friction and backlash in gears by using new, more powerful motors at each joint. CMU has also been developing a general-purpose robot hand for inserting electronic components in printed-circuit boards. This gripper will handle two lead axial devices like resistors and capacitors and three lead devices like transistors.

There are perhaps over 30 other universities in the U.S. performing research in the area of robotics. In general, the most significant area of current research is in vision or tactile sensing, with more than 40% of the average robotics research dollar being allocated to this area. Some of the major universities conducting robotics research are listed below, along with specific research efforts:

- University of Rhode Island

  - Vision system which allows robots to pick randomly distributed objects from a bin.

  - Gripper design including two fingers, articulated hand and multiple hand devices.

- University of Florida

  - Force feedback sensors

  - Robot controls for dynamics underload

  - Robot arm design

- Rensselaer Polytechnic Institute

  - Radar, sonar and IR devices for sensing and identification of objects in robot's path

  - Gripper to unload injection molding machine

  - Robot safety control system

  - Simulation model of Unimation's Puma robot

- Purdue University

  - Vision systems

  - Control systems

  - Robot programming language

- University of Maryland
  - Vision Systems including building models from CAD systems
  - Programming systems for the real-time interactions between sensors and control systems.

- North Carolina State University
  - Vision systems

- University of Central Florida
  - Controls for arm position feedback
  - Robot control language
  - Robot arm design

- University of Cincinnati
  - Vision systems
  - Robot control - dynamics, kinematics, inertia
  - Robot arm design

- George Washington University
    - Sensing in areas of auto-ranging, navigation, mapping and collision avoidance
    - Robot control for integrative feedback
    - Robot programming in a high-level,natural language
- University of Wisconsin
    - Vision systems
- Ohio State University
    - Robot control and dynamics
    - Mobility-legged locomotion system
- University of Texas
    - Vision systems
    - Adaptive robot controls for flexible linkages
- University of Washington

- Vision systems
- Higher level language for robot control using computer vision inputs, other sensors, and geometric modeling.

Non-profit Laboratories

There are only two non-profit research laboratories performing significant research in robotics today, SRI International and Charles Stark Draper Laboratories.

SRI International has been a leader of robotics research in vision systems, robot design and programming languages. SRI is developing recognition techniques, for overlapping parts using variations in light intensity across an object's surface. This essentially gives the robot depth perception and provides the capability to recognize parts that are randomly mixed together. SRI is also conducting research in flexible grippers, voice control and robot assembly applications.

Draper Labs has been conducting research in robotics and automation of manufacturing process for several years, including extensive research in batch assembly applications using robots. Draper Labs has developed a robot wrist accommodator which will be marketed by a firm in Pennsylvania. This device provides the robot hand with the capability of inserting tightly fitting components of irregular tolerances without repositioning the robot arm. Considerable work has also been performed for NASA on the space shuttle remote manipulator system.

Industrial Laboratories

Many large manufacturing companies in the United States are developing robotics research and application laboratories. This includes companies in the automotive, appliance, machine tool, aerospace and computer industries. Most of the research being conducted by industrial laboratories is directed toward applied development rather than in the area of basic research.

Included in this area of industrial research are the development efforts of robot manufacturers. New models are being introduced with superior capabilities, performance, calibration techniques, programming languages, mechanical designs and vision systems. Many robot manufacturers also support research efforts conducted at other laboratories and universities. Several industrial laboratories are described in the following paragraphs.

General Motors Corporation has long been a leader in automation and robotics research. GM's research labs in Warren, Michigan, have made significant contributions to robotics development. The company has developed a vision system which is now in use at GM plants. The PUMA robot was developed by GM working with Unimation for use in automotive assembly operations. In a cooperative effort with Bendix corporation, GM has also developed its own paint spraying robot, which will be used in many GM automotive plants.

Westinghouse Electric Corporation has set up a robotics research laboratory where several different robot models are installed. Westinghouse has also been working with the National Science Foundation to develop an automated production line using robots for assembly. This project (called APAS for Adaptable Programmable Assembly System) began in 1976 and will be completed in 1982.

General Electric Corporation has established an impressive robotics research and demonstration lab. The demonstration laboratory is one of the best equipped facilities in the world. Almost one of every robot manufactured today is available for use in this laboratory. Engineers can get on the spot training and experience using these robots and at the same time evaluate them for specific applications. GE is now marketing the Italian assembly robot called Allegro and has just introduced a line of three robot models.

Several other companies have very aggressive robot research efforts. IBM has developed several programming languages for robots and manufactures its own robot for internal use in assembling small computers and terminals. Texas Instruments, long noted for its automated manufacturing processes for electronic equipment and calculators, has also developed a robot. This robot is for internal Texas Instruments use only and is used to assemble and test hand calculators. Several aerospace companies, such as Martin-Marietta, McDonnell-Douglas, Fairchild, Lockheed, General Dynamics and Boeing, have also conducted robotics research, primarily for NASA and DOD.

Government Laboratories

Government research in robotics has primarily been conducted by the National Bureau of Standards, Air Force, Navy and NASA. The National Bureau of Standards has had an active role in the development of robots. Much of this work has been in the area of vision, force, and proximity sensing for real-time feedback and control. Research has also been conducted in the inspection of machined parts using vision sensors and in the investigation of robot safety issues. A real-time control hierarchy with interfaces to sensors and a system with a data base for programming control has also been developed. NBS is also in the process of developing a completely flexible automated production line using several robots, NC machines, and material handling equipment. This line will be used for R&D efforts by NBS and other researchers.

The Air Force Integrated Computer Aided Manufacturing (ICAM) project in Dayton, Ohio has funded many robotics research programs. These have primarily been contracts with the large aerospace companies to develop applications for robots in the aircraft industry. ICAM has also funded projects to develop off-line programming capability, various sensing devices, grippers and a self-learning capability.

The Naval Air Rework Facility in San Diego, California, has funded several projects to develop applications for robots in aircraft maintenance and repair. This includes the development of robots to remove rivets and fasteners from aircraft wings, to ship and repaint aircraft, and to perform wire harness assembly.

NASA has several robotics projects at its various research centers throughout the U.S. However, the Jet Propulsion Laboratory (JPL) in Pasadena, California, is performing research that is the most relevant to industry. JPL and Stanford University are jointly working on a three finger, three joint robotic hand. This general-purpose gripper, with nine degrees of freedom will enable robots to grasp a variety of differently shaped parts.

As a result of the research conducted by these and other organizations, the future of the robotics industry looks promising. The industry is presently growing at 35-50% per year, and many experts believe that this trend will continue during the next several years.

FUTURE TRENDS

In 1979, a total of about 700 robots were installed in the U.S., which amounted to a sales volume of $65 million. In 1980, sales increased to $90 million, and in 1981 a volume of $125 million is estimated, resulting in a total installed base of about 4,500 robots as of the end of 1981. During the next decade, this rapid growth is expected to continue, with an estimated annual sales volume of $2 billion per year reached by 1991. Annual unit sales by 1991 would be in the range of 60,000-80,000 robots per year.

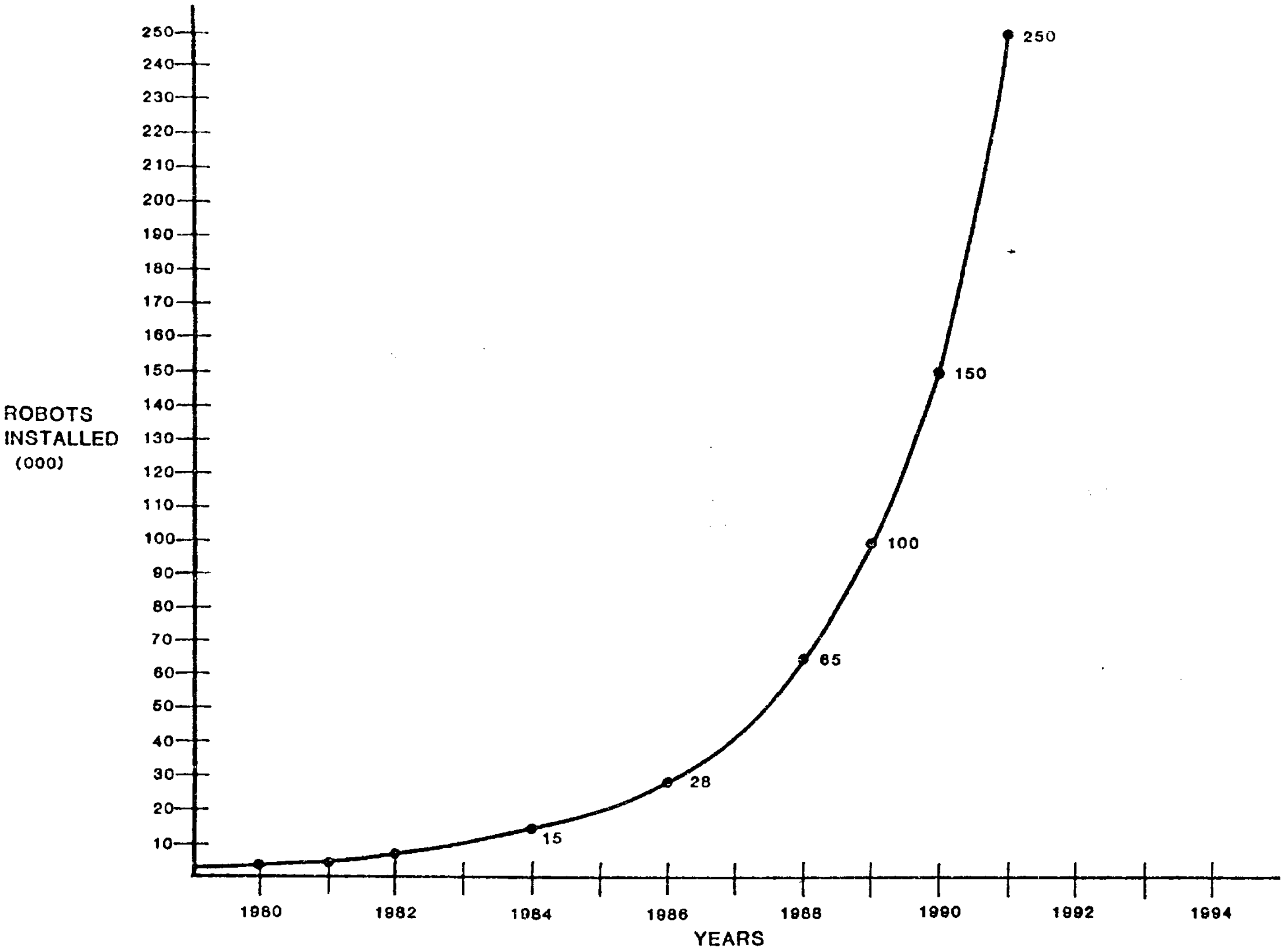
As seen in Exhibit 28, if this sales growth is achieved, the total installed base of industrial robots can be expected to increase from the current 4,500 to about 250,000 robots. As discussed in Chapter 3, there are probably 1-3 million potential robot applications in U.S. manufacturing operations, and so robots can be expected to be used in some 8-25% of all manufacturing applications for which they make sense by 1991.

As robot applications continue to increase, prices are expected to decrease. Most robot manufacturers expect that the average price of a typical robot installation will decrease by 15-20% over the next five years. An even greater decrease in price is expected over the next ten years.

As the total number of robots increases, the nature of the applications in which they are used can be expected to change. As seen in Exhibit 29, the areas of most significant growth are expected in assembly, machining, and arc welding. By 1991, assuming that improvements are achieved in sensing capabilities, assembly robots could account for 20-25% of all robots used in industry. Arc welding robots should increase in usage with the development of an improved seam tracking sensor. In general, these projections assume that technological improvements will be achieved in the areas of robot strength, accuracy, vision sensing, contact sensing, and higher level programming languages. In addition, it is assumed that robot applications will increase as manufacturing managers become increasingly aware of robot capabilities.

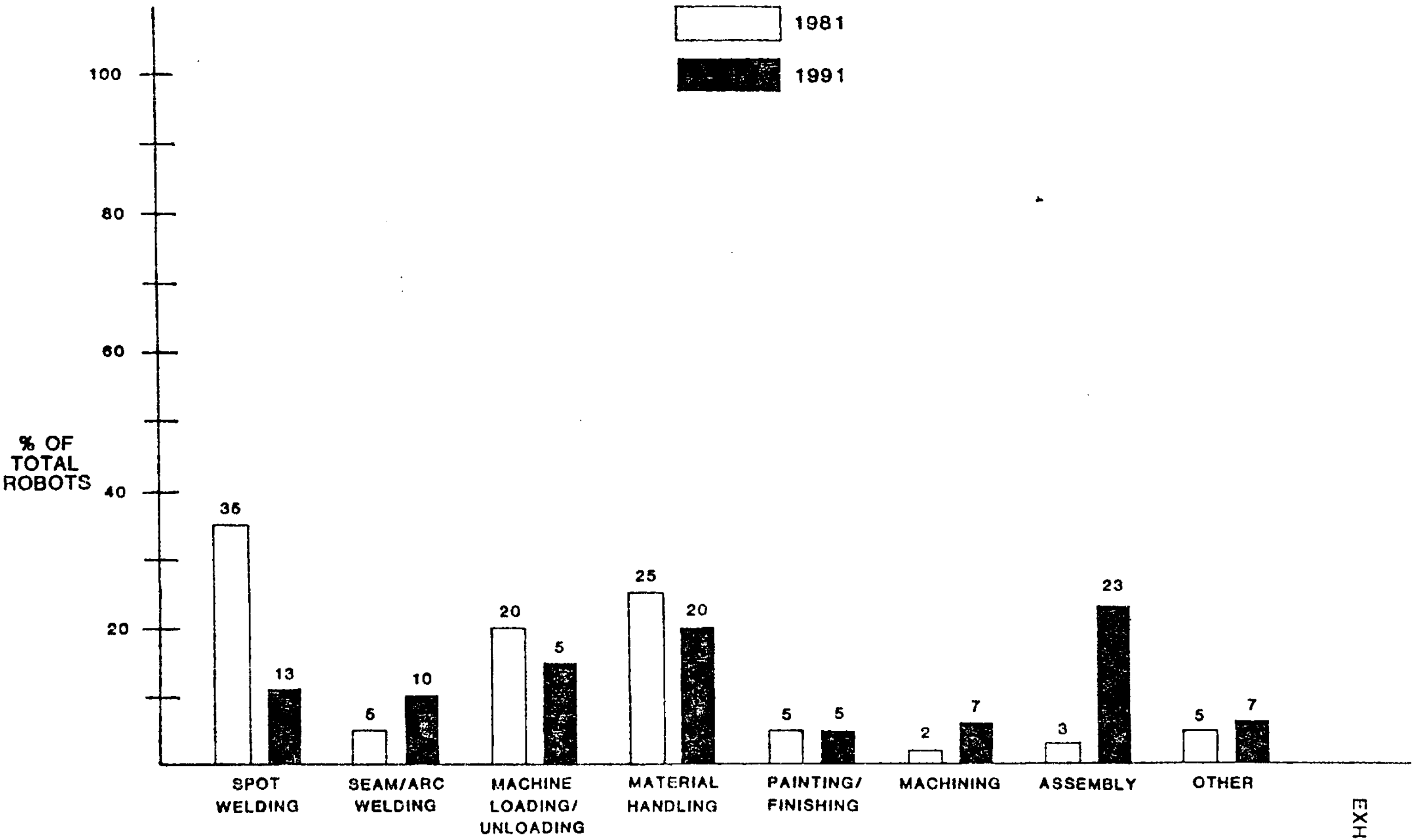
The technological and economic developments required for these growth projections to be achieved are likely to emerge from the

EXHIBIT 28



CUMULATIVE TOTAL OF U.S. ROBOTS

EXHIBIT 29



U.S. ROBOT APPLICATIONS

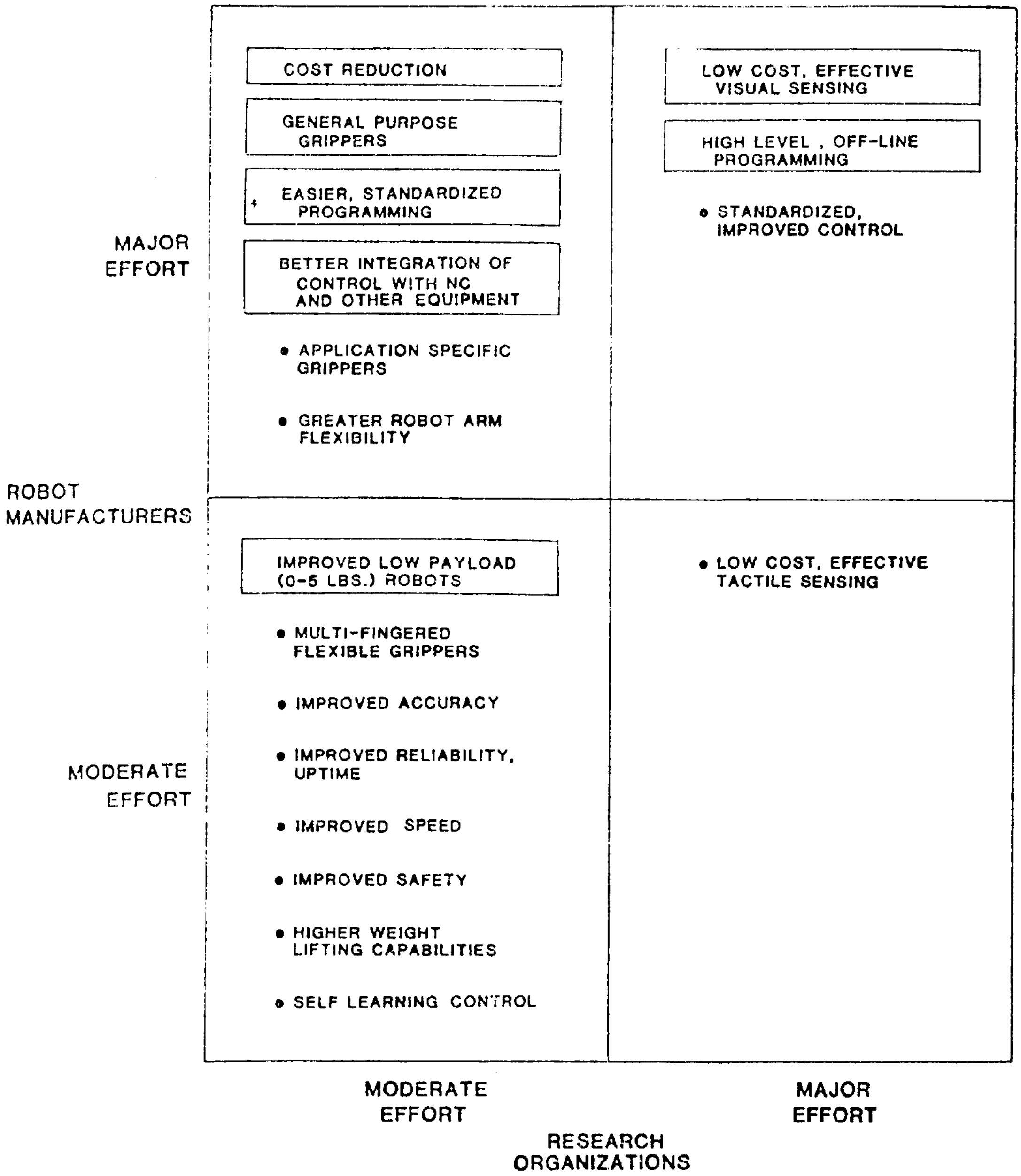
research and development efforts of the organizations discussed earlier. Many development programs are in the final prototype stage, and several improvements can be expected to be incorporated into robot designs within the next five years. Several significant developments that can be expected within five years are shown in Exhibit 30. This chart shows the extent to which robot manufacturers or research organizations are concentrating their efforts on each area, along with the developments which are likely to have the greatest impact on the robot industry. To support these efforts, research budgets in the robotics field are increasing rapidly. Research organizations project average increases of 30-40% per year in their robotics research budgets over the next five years.

The area having the greatest potential impact on the growth of the robot industry is the development of a low cost, effective vision system. There is more research being conducted in this area than all others combined. An effective vision system which will allow a robot to "see" will lead to a major advance in robot sales, particularly if it is not expensive. Today's vision systems do not have the processing speed, resolution, adaptive control, or the price required to allow widespread use of robots in applications such as assembly and inspection operations. However, with the development of 32-bit and larger microcomputers, and with advances in control methodology, the development of effective vision systems will be just a matter of time.

An area which is also likely to have a significant impact on the number of robots used is the capability of programming them off-line. This capability would greatly enhance their economic viability in small batch production jobs, which account for the majority of U.S. production output. Off-line programming provides the capability of developing new programs without taking the robot off the production line. In order to attain this capability, increased accuracies, improved computer interfaces, and easier programming languages need to be developed. This technology is near and could be realized within

EXHIBIT 30

SIGNIFICANT ROBOT DEVELOPMENTS EXPECTED WITHIN 5 YEARS, AND CURRENT LEVEL OF DEVELOPMENT EFFORT



ROBOT MANUFACTURERS	RESEARCH ORGANIZATIONS: MODERATE EFFORT	RESEARCH ORGANIZATIONS: MAJOR EFFORT
MAJOR EFFORT	COST REDUCTION GENERAL PURPOSE GRIPPERS EASIER, STANDARDIZED PROGRAMMING BETTER INTEGRATION OF CONTROL WITH NC AND OTHER EQUIPMENT • APPLICATION SPECIFIC GRIPPERS • GREATER ROBOT ARM FLEXIBILITY	LOW COST, EFFECTIVE VISUAL SENSING HIGH LEVEL , OFF-LINE PROGRAMMING • STANDARDIZED, IMPROVED CONTROL
MODERATE EFFORT	IMPROVED LOW PAYLOAD (0-5 LBS.) ROBOTS • MULTI-FINGERED FLEXIBLE GRIPPERS • IMPROVED ACCURACY • IMPROVED RELIABILITY, UPTIME • IMPROVED SPEED • IMPROVED SAFETY • HIGHER WEIGHT LIFTING CAPABILITIES • SELF LEARNING CONTROL	• LOW COST, EFFECTIVE TACTILE SENSING

NOTE: ☐ INDICATES DEVELOPMENTS LIKELY TO HAVE A MAJOR IMPACT ON ROBOT USAGE IN INDUSTRY two or three years, because research organizations and robot manufacturers are both conducting major research and development efforts in this area.

Another area which would certainly increase the utilization of robots is the development of a general purpose gripper. Today's robots, almost without exception, use special purpose grippers for each application. These grippers can be very expensive, and they can be difficult and time consuming to install. A general purpose gripper would reduce the initial cost of a robot system, allow easier setups between jobs, and reduce the operating costs of the robot. A general purpose gripper using jointed fingers for grasping objects has been designed and could be developed within the next five years. Gripper development efforts are primarily being conducted by robot manufacturers.

Finally, robots are expensive and have only recently become economically competitive with human labor in many applications. Robot costs are generally considered to be too high at present. If the cost of robots decline, significant increases in the number of robots will result. It is projected over the next five years that the cost of a robot will decline by 15-20% (in constant dollars), and possibly by as much as 50% over the next ten years. This cost reduction will result from higher robot production rates and the continued decrease in the cost of electronics.

A reduction in the cost of robots will have several effects on the robot industry. First, less expensive robots will enable many smaller manufacturing firms who cannot afford large capital investments to purchase robots. Secondly, a lower cost will increase the number of possible applications for robots by making them more cost competitive with human labor. Lastly, increased demand for robots could entice more companies to enter the robot industry.

Several large companies, such as General Electric and GCA, have just recently entered into the robot market. Several other companies, such as IBM, Texas Instruments, Westinghouse and Bendix are monitoring developments in the market very closely. The effect on the robot industry should these or similar large companies enter the market would be significant. These companies could capture a substantial share of the industrial robot market because of their large industrial bases, sophisticated product technologies, and strong marketing organizations.

With several new companies entering the robot market, it is expected that industry sales five years from now will not be as concentrated as in today's market. Six companies today account for an estimated 93% of sales. By 1986, eight to ten companies should account for 80% of sales. After that time, a shakeout period should occur, in which many weaker companies withdraw from the market. During the 1990's, there should once again be five or six major companies that dominate the market.

Although the robot industry has been in existence for over two decades, it is just now showing signs of becoming a high growth industry. A forecast of high growth in the future is based upon a combination of improved robot capabilities, reduced cost, increasing direct labor costs, and increasing awareness of robot capabilities and applications.

SELECTION AND IMPLEMENTATION OF ROBOTS

The successful purchase and installation of an industrial robot requires that the entire process be planned and carried out in a logical sequence. Although the basic steps to be followed are similar to those in the case of any other type of automation, robots have unique capabilities and limitations that make it especially important to carefully plan the implementation process. Disappointments can result in cases where users have unrealistic expectations of robot capabilities or performance. As discussed earlier, robots combine certain capabilities of both manual labor and hard automation, and so the types of applications for which they are best suited and the way they are likely to perform may not be immediately obvious.

The entire process of implementing a robot, from the initial planning through the ongoing operation of the robot on the production line, requires that four general steps be completed:

1. Planning - Before selecting and installing a specific robot, a planning phase is required to evaluate the nature of the production operation(s) for which robots are being considered and to determine that robots are justifiable. By the end of this phase, a decision will have been made that robots should be used, and likely candidates for applications will have been determined.

2. Applications Engineering - During this phase, the candidate applications are studied in more detail, a specific first application is selected, and a specific robot is selected. In addition, detailed requirements for the application are analyzed, such as layout requirements, workplace modifications, and robot accessories required.

3. Installation - This phase covers the time from the preparatory work performed on the workplace through the installation and start up of the robot.

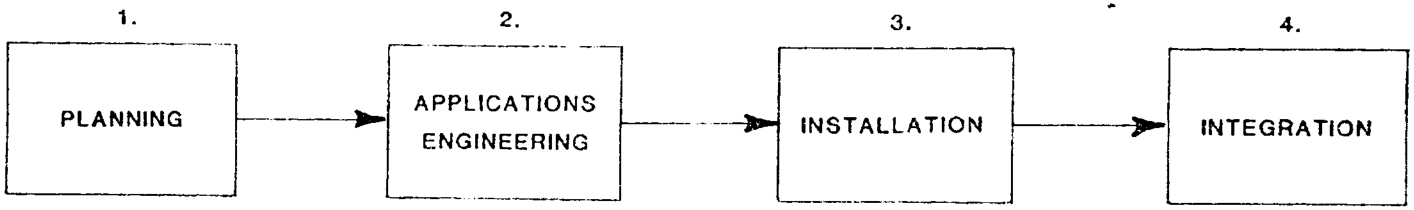
4. Integration - Once the robot has begun operation, an ongoing process is required to insure that it continues to perform its job in an effective manner. Activities to be performed during this phase include maintenance, monitoring, human relations, and the constant upgrading of the robot through the use of new technologies or the application of the robot to new manufacturing operations.

The remainder of this chapter examines the specific activities that should be performed during each of these phases in order to insure that the robot is implemented in an orderly, logical manner. A flow diagram of the implementation process outlined here is shown in Exhibit 31.

PLANNING

This essential first step in the implementation process can have a major impact in determining the eventual success of a robot installation. During this phase, the question of whether or not a robot installation makes sense is considered, and a go/no-go decision is made. As in the case of other types of automated machinery, the initial decision to begin considering robots for use in manufacturing operations typically begins with manufacturing/production engineering personnel. However, because robotics represents a progressive new technology, many current users report that top management was also involved in the initial decision to consider robots. Most companies now using robots did not conduct a formal audit of their manufacturing operations to evaluate the feasibility of using robots or to identify

PROCESS OF PLANNING, SELECTING, AND IMPLEMENTING ROBOTS



1. PLANNING
- ORGANIZE PROJECT TEAM
- DEFINE OBJECTIVES
- IDENTIFY ROBOT APPLICATION CANDIDATES
- REVIEW ROBOT EQUIPMENT
- CONDUCT ECONOMIC ANALYSIS

2. APPLICATIONS ENGINEERING
- SELECT INITIAL APPLICATION
- SELECT ROBOT
- STUDY INITIAL APPLICATION REQUIREMENTS

3. INSTALLATION
- PREPARE FOR INSTALLATION
  - -WORK AREA
  - -TOOLING
  - -SAFETY
  - -TRAINING
- INSTALL AND START UP

4. INTEGRATION
- MONITOR PERFORMANCE
- CONDUCT MAINTENANCE
- UPGRADE FOR NEW APPLICATIONS OR TECHNOLOGIES

EXHIBIT 31

likely applications. However, they did conduct cost studies to evaluate the economics of using robots rather than manual labor. In typical manufacturing operations, it makes sense to conduct both a cost study and an audit of manufacturing operations.

Specific steps that should be followed during this phase are discussed in the following sections.

Organize Project Team

The first step that should be completed during this phase is the selection of a group of individuals to carry out the implementation program. This group typically includes the plant manager, production supervisory personnel, and engineering management personnel. All three levels of management must actively participate in the entire process in order to insure a successful implementation. The plant manager must be involved to provide overall policy direction for the project and to provide inputs into the evaluation process. Although the plant manager will not become involved in the details of applications engineering or installation, it is important that the benefits and limitations of robots be made clear to him so that the decision can be properly viewed within the context of corporate objectives and guidelines.

The production management representative should be involved in the entire process from beginning to end, since this is the individual who understands the characteristics of each manufacturing operation better than anyone else. The engineering staff representatives should become thoroughly familiar with the technical and performance characteristics of the robot. These individuals will be involved in the applications engineering and installation phases. Since a robot is a dynamic rather than a static machine, it is important that engineers who specialize in dynamics be assigned to the project team.

In addition to this group, it is important that upper and middle management of the company be provided with ongoing information regarding the status of the project. Initially, they will require a thorough analysis of the rationale behind the decision to consider robots, including overall benefits to the company. Over time, a series of progress reports will be necessary.

Define Objectives

Once the project team has been assembled and responsiblilities have been defined, it is necessary to define the objectives to be accomplished in installing robots in the plant. As discussed earlier, there are a number of potential benefits to be realized in using robots, including higher productivity, reduced costs (labor, materials, and others), higher product quality, improved employee morale, or simply the enhanced corporate image resulting from the use of a sophisticated technology. The specific objectives of upper management should be clearly defined as a basis for evaluating the desirability of using robots. Most companies now using robots view cost reduction as the primary objective that is satisfied in using robots.

Identify Robot Application Candidates

The next step is to conduct a review of the manufacturing environment being considered for robot applications. The goal of this review is to identify a set of suitable application candidates for the use of robots. It is important that the robot concept be considered as a whole when examining potential applications. The entire manufacturing operation should be studied as a system for compatibility with the concept of robotics. In this way, patterns will begin to emerge in various applications where robots clearly would offer certain advantages.

It is useful to use some form of a "robot application checklist" for assessing the general feasibility of robots in each application being considered, such as the example shown in Exhibit 32. In this checklist, there are a set of basic requirements which must be satisfied in order for robots to be suitable for the application. If any one of these requirements are not met, then probably either fixed automation or manual labor would be a better choice than robots. The second category of criteria shows several other conditions in which robots are likely to be preferable over fixed automation or manual labor. To evaluate the relative attractiveness of robots in each application, some form of a rating scale can be applied, such as a simple 0-10 scale to evaluate how well a robot is likely to satisfy each criterion. If appropriate weights (0-10) are assigned to each criterion to evaluate the relative importance of each in the eyes of management (as in the example), then a factor weighting score can be developed for each alternative by multiplying each weight by the corresponding rating and adding all resulting scores. This will provide a rough initial indication of the areas in which robots are likely to perform best.

In general, the best initial applications for a robot are those in which there have been safety problems in the past. The project team will have the least amount of difficulty justifying these applications to management. Another good area to consider is an operation that is boring, fatiguing, or environmentally unpleasant, and therefore, has been characterized by high absenteeism or poor performance. Finally, an operation in which there has been a high degree of wasted materials or scraps as a result of human efforts, such as in spray painting overshooting, can be a good initial candidate for robots. Photographs of material waste can provide

EXHIBIT 32

ROBOT APPLICATION CHECKLIST

	WEIGHT	APPLICATION CANDIDATES					
		1.		2.		3.	
		YES	NO	YES	NO	YES	NO
BASIC REQUIREMENTS							
ORDERLY ENVIRONMENT							
REPETITIVE OPERATION							
CYCLE TIME OVER 3 SECONDS							
NO JUDGEMENT REQUIRED							
UNIFORM PARTS							
MEETS INVESTMENT CRITERIA							
DESIRED CHARACTERISTICS							
HAZARDOUS ENVIRONMENT	10						
MONOTONOUS OPERATION	9						
DIFFICULT HANDLING	8						
MULTI-SHIFT OPERATION	7						
MEDIUM PRODUCTION VOLUME	7						
MEDIUM COMPLEXITY OPERATION	6						
MANAGEMENT SUPPORT	4						
WORKER/UNION SUPPORT	4						
IMPROVED PRODUCTIVITY	4						
IMPROVED PRODUCT QUALITY	3						
POTENTIAL FOR SEVERAL ROBOTS	3						
FEW INSTALLATION PROBLEMS	2						

strong supporting evidence when justifying the robot.

In general, the types of applications suited for robots are those which are capable of being performed by robots (work envelope, load capacity, dexterity, etc.), do not require judgment by the robot, and in which the use of a robot can be justified, as shown on the applications checklist example. When studying an application, it is important to think in terms of the job to be done rather than to decide whether or not a robot can simulate a human worker. In a spot welding application, for example, the task is to place a specified number of welds at specified locations. The fact that certain welds may be inside a large part and difficult for humans to reach is irrelevant in considering the use of a robot other than the fact that humans may not enjoy doing the work. A robot can easily be supported from the ceiling, if necessary, in order to reach certain locations.

Throughout this process, it is important to continually think in systems terms. The goal is not to identify applications in which robots can be modified to meet the needs of the work environment. Rather, the goal is to effectively integrate the robot, the workpieces, the conveyors, other machines, human workers, facilities, and computers into a productive manufacturing system. Always begin by defining the task to be performed rather than by thinking of human capabilities.

Review Robot Equipment

After generating a list of potential candidates for robot applications, the next step is to learn as much as possible about the categories, brands, and models of robots that are currently available. After determining what types of applications are being considered, this task can be simplified somewhat. For example, if the candidate application is spray painting, then the search can be limited to continuous path robots. If a machine loading application is being considered, then a more sophisticated servo robot would likely be required.

A summary of capabilities for each robot being considered for each application should be prepared. The robot specification summary tables discussed in Chapter 2 provide this information for most robots available in the U.S. as of the end of 1981. The specifications of these robots can then be compared with the requirements of each application to determine which robots may be suitable for the job.

Conduct Economic Analysis

The final step during the planning phase is to conduct a cost justification study for several of the most likely initial application candidates, using the robot brands that appear to be most suitable as examples for initial cost estimates. Although certain non-economic factors, such as worker safety and morale, are often cited as being justifications for the use of robots, it is ultimately the economic considerations which determine whether or not a company will use them. Economic considerations are especially important when deciding whether or not to purchase a piece of equipment that can easily cost as much as $100,000-$200,000. Although justification criteria are often divided into economic and non-economic factors, all factors have an economic impact in a manufacturing environment. For example, in a hazardous environment, there are specific costs associated with the safety precautions necessary to protect human workers. These costs can be compared with the costs of using robots in place of human workers.

There are two general ways of looking at the costs to be considered in analyzing the use of robots versus manual labor or hard automation. The first approach, cost avoidance, is used to evaluate the least costly of several alternative investments. For example, in a machining operation involving drilling holes in metal parts, the cost of installing a robot would be compared with the cost of safety clothing, goggles, and guards for human workers. The robot would require none of these safety features, and therefore, certain costs would be avoided. In addition to these costs, an analysis would then have to be performed on the potential labor cost savings or change in productivity in using a robot.

The second type of analysis is a study of cost savings. In this case, one or more alternatives are compared with the "do nothing" alternative to evaluate the likely investment return to be achieved under each alternative. Although a detailed discussion of the various approaches used to evaluate investment alternatives is beyond the scope of this report, it is useful to note that three basic approaches are commonly used in manufacturing firms today to compare alternative projects:

- Return on Investment (ROI). This is probably the most commonly used tool for comparing alternative investments. A series of annual cash flows are developed for each alternative, taking into account both expected annual cost savings and expenses. These cash flows are then compared with an initial investment, or cash outlay, to determine an overall annual rate of return on the investment. This return is then compared with a minimum investment criterion to evaluate the attractiveness of each alternative.

- Net Present Value (NPV). Under this approach, a series of discounted annual cash flows are generated for each alternative over the life of the project (e.g., 10 years). The discount rate is usually equal to the cost of securing capital for the company, which today may be as high as 20%. These discounted cash flows (which are hopefully positive numbers) are added and compared with the initial cash investment. If the sum of the discounted cash flows is larger than the initial investment number, then the difference between the two represents the present value of the alternative to the company. This must be a positive number in order for the alternative to meet the company's investment return criterion.

- Payback Period. This is a measure of the time required to recover the initial investment costs for each alternative. For example, if a payback period is three years, this means that the sum of the cash flows during the first three years is equal to the initial investment cost. After three years, the project will then generate positive net dollars. A simple payback period for robots can be defined as follows:

$$P = \frac{R - T}{(L + M - C)(1 - t) + D\,t}$$

Where:

P = Payback period (years)
R = Total cost of robot
T = Investment tax credit
L = Annual direct labor cost savings
M = Annual material cost savings
C = Annual maintenance and operating cost for robot
t = Tax rate
D = Annual depreciation

This equation is adequate when the payback period is very short, such as one or two years. However, a more realistic payback period would consider the time value of money by using discounted cash flows. In the case of industrial robots, which have relatively short paybacks, this equation represents a good approximation.

The net present value approach provides the most realistic and meaningful comparison of several investment alternatives. In the case of a new technology such as robotics, however, payback period may be a more useful short term means of preparing an economic justification of a potential robot installation. Most robot manufacturers claim that a payback period of from one to two years is likely. Companies that have used robots report an average payback period of two years, which is generally an acceptable number for most manufacturing equipment.

To evaluate the net present value or payback of a particular robot in a particular application, a financial analysis form such as that shown in Exhibit 33 can be used. The example shown here is a typical high technology robot costing $ 120,000 (total cost, including accessories and installation, with an investment tax credit already deducted). Operating savings amount to $ 52,500 per year (assuming a three shift operation and a depreciation rate of 10% per year). When depreciation is added back (after deducting income tax) to generate a cash flow, the payback period is seen to be about 1.5 years. Note that this is a discounted payback, using a discount rate of 20% for convenience.

In actual cases, there are many areas of potential cost savings that may be realized. Some of the more common categories of cost savings include the following:

- Direct labor (assuming one human worker per robot per shift)

- Cost avoidance (e.g., a potential lawsuit because of

SAMPLE ROBOT ECONOMIC ANALYSIS FORM

	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 9	YEAR 10
EXPENDITURES										
1. ROBOT	$66,000									
2. ACCESSORIES	30,000									
3. INSTALLATION	18,000									
4. SPECIAL TOOLING	6,000									
5. OTHER (10% TAX CREDIT)	(12,000)									
6. TOTAL	$108,000	0	0	0	0	0	0	0	0	0
OPERATING SAVINGS (COSTS)										
7. DIRECT LABOR	$70,000									
8. INDIRECT LABOR	(1,500)									
9. MAINTENANCE/REPAIR	(3,000)									
10. OPERATING SUPPLIES	(1,000)									
11. (DEPRECIATION)	(12,000)									
12. OTHER SAVINGS (COSTS)										
13. TOTAL	$52,500									
ANALYSIS										
14. TOTAL EXPENDITURES	$(108,000)	0								
15. TOTAL SAVINGS	52,500	52,500								
16. NET BEFORE TAX (15-14)	(55,500)	52,500								
17. NET AFTER TAX (16 x .52)	(28,860)	27,300								
18. NET CASH FLOW (17-11)	(16,860)	39,300								
19. DISCOUNT FACTOR (20%)	.833	.694	.578	.482	.402	.335	.279	.233	.194	.162
20. DISCOUNTED CASH FLOW (18 x 19)	(14,050)	27,274	22,715	18,943	15,799	13,165	10,965	9,157	7,624	6,367
21. CUMULATIVE CASH FLOW	(14,050)	13,224	35,939	54,882	70,681	83,846	94,811	103,368	111,592	117,959

NET PRESENT VALUE = $118,000

PAYBACK = 1.5 YEARS

EXHIBIT 33

a faulty weld)

- Elimination of safety clothing items, such as safety shoes, goggles, gloves, and aprons
- Elimination of guards around exposed tools
- Reduced scrap rate and rework
- Reduced energy costs
- Reduced administrative/supervisory costs
- Elimination of human facilities, such as washrooms, parking, and dining area

Although some of these items represent areas of relatively small savings, they should all be considered in the cost analysis in order to further justify the use of a robot.

APPLICATIONS ENGINEERING

The second phase of the process involves the selection of the specific application area for which the first robot(s) will be employed, the selection of the robot to be purchased, and the detailed analysis of the application in order to prepare for installation.

Select Initial Application

The list of application candidates can be narrowed by reviewing them with several robot manufacturers who produce robots that appear to be suitable. A more detailed study of each application can also help narrow the list. It is extremely important that the correct initial application be selected. If this first application fails, it could also be the last. It is probably best to select the simplest application from the list of candidates, assuming that the potential benefits appear to be reasonable. The objective of the first installation is to prove that the technology works and can significantly improve some aspect of the manufacturing environment. As discussed earlier, an application in which there is a record of safety or health problems is an ideal first application.

The selected first application should be studied in detail. Every task that must be performed should be documented, not in human terms, but in terms of the end result to be achieved. The required robot work envelope should be defined, and all capabilities (load, speed, cycle time, accuracy, etc.) should be specified. If at any step a task is discovered that is beyond the capability of a robot, another alternative should be considered. It is important at this point to think like a robot and consider all of the possible things that can go wrong.

Another consideration is a potential backup for the robot during the 2-4% of the time that it is likely to be out of service for maintenance or repairs. Space requirements, safety considerations, and load capacity should be also considered during this time. The objective during this step is to make certain that the selected application is the best one possible for testing the performance of the robot.

Select Robot

The process of selecting the robot is the same as that for any other piece of automated equipment. Several manufacturers should be contacted for information and advice. Although the robot manufacturer is the most important source of information in learning about robots, many users have obtained valuable information by talking to others who had used robots in their manufacturing operations. It is probably more important to review several sources of information when selecting a robot than for other types of manufacturing equipment, in part because the capabilities and performance of robots are not always immediately obvious. Many robot purchasers also find valuable information available at conferences and trade shows, such as those sponsored by the Society of Manufacturing Engineers (SME). Although very few independent consulting firms exist to provide assistance in selecting robots, it is likely that the number of such firms will increase in the future as the number of robot installations increases.

A demonstration of a robot in operation can be extremely helpful. About half of all companies now using robots report that they were able to see a robot in operation at a demonstration facility operated by a robot manufacturer. It may also be possible to visit a company that is using robots, although many companies are reluctant to allow outside visitors to observe their robot operations. Films of robots in operation provided by many robot manufacturers can also be useful.

Study Initial Application Requirements

After selecting the robot, the application should be studied to prepare for the installation of the robot. A layout of the installation should be prepared, using a scale model if possible, to determine what engineering requirements will need to be satisfied before installing the robot. The specific areas to be studied include the following:

- Protection for the robot from environmental hazards, such as dust contamination, metal particles, heat, chemical corrosion, cold, and paint overspray.

- Obstacles or interferences with the movement of the manipulator arm.
- Interfaces required between the robot and other machines, conveyor lines, computers, or other items.
- Tooling requirements, such as special fixtures or tooling changes required to locate the workpiece at a precise position relative to the robot.
- Safety precautions to protect personnel working near the area. Although the overall safety record of robots has been good, the manipulator arm can impart serious injuries to workers who mistakenly enter the work envelope of the robot. Therefore, guard rails are essential. The control console should also have an emergency stop button.
- Provisions for utilities, such as electricity, compressed air, and water.
- End-of-arm tooling or gripper design. Although robot manufacturers are working on the development of standardized grippers, it is still normally the task of the user's applications engineering group to design end-of-arm tooling. A great deal of creativity can be applied here, and most robot manufacturers will provide assistance.
- Spare parts and test equipment for the robot system.
- Other changes in facilities, equipment, or plant layout that may be required.

Most robot users agree that the applications engineering step is an extremely important part of the robot implementation process. Many feel that the existence of a formal applications engineering function in a plant is a definite advantage. During this step, a creative approach to robot applications should be followed. For example, product design changes may result in a much improved robot performance, whereas human performance might not be improved. Creative layouts, using upside-down robots, represents another approach, as does the reorientation of parts being fed to the robot.

INSTALLATION

Installation times for robots currently in use have ranged from 3-4 days up to 90-100 days. On the average, a typical robot installation requires a total time of about three weeks. This is a significant amount of time, and it pays to prepare for the task by completing several preparatory activities.

Prepare for Installation

It is wise to perform as much preparatory work as possible before the robot is installed in order to insure a smooth operation. Preparation for installation requires that facilities, equipment, and people are prepared for the robot.

Work Area

Service drops and preparation of the floor can be completed before installing the robot, based upon the requirements determined during the applications engineering step. Certain interfaces with other equipment can be prepared. If a product design is being modified or if the work flow from an upstream work station is being changed, this can also be accomplished before installation. Equipment can be relocated and conveyor lines can be rearranged. The work area must be rearranged in about three-fourths of all robot installations, especially in welding or material handling operations.

Development of Tooling

End-of-arm tooling can be developed before installation. Working with robot manufacturers, companies can develop custom made end effectors and grippers, and they can also rework existing tooling with which the robot would interface.

Safety

Guard rails and safety chains can be prepared before the robot is installed. The Occupational Safety and Health Act (OSHA) is the primary government regulation that affects the safety requirements of robots. Although OSHA regulations do not govern robot usage directly, the use of robots for reducing or eliminating risks tends to satisfy many OSHA standards. Therefore, when robots are being considered for use in potentially hazardous environments, it is useful to consider their ability to satisfy such OSHA regulations as:

- Sub-part G, Occupational Health and Environmental control
- Sub-part H, Hazardous Materials
- Sub-part I, Personal Protective Equipment
- Sub-part L, Fire Protection

- Sub-part N, Materials Handling and Storage
- Sub-part O, Machinery and Machine Guarding
- Sub-part P, Hand and Portable Power Tools
- Sub-part Q, Welding, Cutting, and Brazing
- Sub-part S, Electrical

Training

It is extremely important that all individuals who will be involved in the operation of the robot be thoroughly trained in its technical capabilites, operation, programming, and maintenance. This training should be conducted before installing the robot. At least two people, including maintenance personnel, manufacturing and applications engineers, production workers, and in some cases the plant manager, should attend a 3-5 day training program that is increasingly being offered by robot manufacturers. These programs can be held either at the robot manufacturer's facility or at the customer's plant. Programming training is especially important, since robot programming capabilities have not yet been standardized.

Human Relations

The importance of securing the support of personnel should not be underestimated. Many people believe that robots are likely to replace workers rather than displace them. Two key areas of human relations must be attended to before installing a robot. First, the commitment of management must be assured. This is readily accomplished if the planning and applications engineering phases have been correctly conducted and a logical justification for robots has been presented.

The second area is more complex, since it requires that the workers who are either being displaced or who must work with the robots accept them willingly. Workers must be shown that the use of robots means that they will no longer be required to perform certain unpleasant activities. They must be convinced that their jobs will be upgraded, not eliminated. The experience of companies using robots has been very favorable in this area, with workers generally being positive about the robots.

Union relations must also be considered before the robot is installed. Unions have generally been receptive to robots, especially when presented with facts showing the improvement in working conditions likely to result after the robot is installed. In addition, unions must be shown that worker jobs will not be endangered, and that provisions will be made for employee retraining. Finally, unions will want assurance that robots will not be used to set new performance standards for humans.

Install and Start Up

If the preliminary preparations have been properly conducted, the actual installation of the robot should be smooth. Most manufacturers will offer installation assistance, although it is preferable for a company to use its in-house staff, so that the personnel who will have to work with the robot can become more familiar with it. Some companies prefer to conduct several days or weeks of testing with the robot before installing it on a production line. Robots do not experience a learning curve as do humans. However, there is likely to be a start-up period required during which initial problems must be resolved. Most of the difficulties experienced by companies in installing robots are related to problems in programming, which points out the importance of programming during the training program. Typically, a period of less than one day up to several weeks or even months may be required to reach a 100% production level.

INTEGRATION

After the robot has begun production operations, the period of integrating the robot into the production environment begins. This is the period during which the robot is transformed from a curiosity into an accepted, standard piece of production equipment. It is difficult to estimate a time for this phase, since it is an on-going task. The first part of this phase begins with the monitoring of the robot to watch for recurring problems, keep track of robot performance, monitor downtimes, and evaluate the acceptance of the robot by management and by the production workers. In addition, the robot should be monitored to insure that the economics of the operation are achieving the predicted results.

On-going maintenance is also a part of the integration phase. It is advantageous to have an in-house maintenance capability rather than to rely on a robot manufacturer service contract. Maintenance personnel should be given total responsibility for the performance of the robot. One difficulty with this approach is that robots are highly reliable, and so it may be difficult for an in-house maintenance staff to achieve a constant level of proficiency. One way to offset this is to provide for periodic retraining of the maintenance staff.

Another area of activity during this phase is to constantly search for ways to upgrade the robot system, by using robots in new applications, by adding on new technological developments, or by using groups of robots working together. As new ways of using robots are learned, their overall performance will improve, and worker acceptance is likely to increase. The ultimate goal in using a robot system is to integrate it into the manufacturing environment to the extent that it is viewed as simply a standard type of manufacturing technology rather than as a unique piece of equipment.

NEXT STEPS

It was pointed out earlier that there is no reason to wait for improvements in robotics technology before deciding to install a robot system. Current, technology is adequate for robots to perform a large number of manufacturing operations. Even if no changes were made in robots during the next decade, the growth in the number of robot installations would still be significant. Currently available robots have just begun to reach their full potential.

With so much activity taking place in the robot industry, this is an excellent time to consider the purchase of a robot. Robot manufacturers are willing to offer a great deal of assistance to prospective purchasers, from the initial planning process through installation and maintenance operations. There is also a large volume of published information available, including reports, articles, and product literature. The best time for a prospective purchaser to begin studying robots is now, while the industry is still in the process of defining itself.

As an aid in getting started, the Appendices that follow present several helpful lists of information sources. The first Appendix is a selected list of some of the most useful sources of published information currently available on robotics and a list of manufacturers, research organizations, and associations involved in the robotics field. The second Appendix is a glossary of selected terms in the robotics field.

APPENDIX A

SELECTED LIST OF ROBOTICS ORGANIZATIONS AND INFORMATION SOURCES

BOOKS, REPORTS AND PUBLICATIONS

Engelberger, J.F., "Robotics in Practice," Amacom Division of American Management Associations, 1980.

Tanner, William R., "Industrial Robots," Volumes I and II, Society of Manufacturing Engineers, Dearborn, Michigan, 1981.

" A Survey of Industrial Robots," First Edition, Productivity International, Inc., 1980.

Parsons, H. M., and Kearsley, G.P., "Human Factors and Robotics: Current Status and Future Prospects," Human Resources Research Organization, October, 1981.

Fisk, J.D., "Industrial Robots in the United States: issues and Perspectives," Congressional Research Service, The Library of Congress, Report No. 81-78 E, March 30, 1981.

Toepperwein, L., Blacknow, M.T., et al, "ICAM Robotics Application Guide", Report AFWAL-TR-80-4042, Vol. II. Air Force Wright Aeronautical Laboratories, Materials Laboratory, Wright-Patterson Air Force Base, Ohio, 1980.

"Proceedings--Tenth International Symposium on Industrial Robots and Fifth International Conference on Industrial Robot Technology," Milan, Italy, March 5-7, 1980.

"Proceedings--Robotics III Conference," Society of Manufacturing Engineers, November 7-9, 1978.

"Proceedings--Robots IV Conference," Society of Manufacturing Engineers, October 30-November 1, 1979.

"Proceedings--Robots V Conference," Society of Manufacturing Engineers, October, 1980.

PERIODICALS

Industrial Robots International
158 Linwood Plaza
P.O. Box 1304
Fort Lee, N.J. 07024
(201) 944-6204

Robotics Age
P.O. Box 725
La Canada, CA 91011

Robotics' Today
One SME Drive
P.O. Box 930
Dearborn, MI 48128
(313) 271-1500

DIRECTORIES

1982 Robotics Industry Directory
P.O. Box 725
La Canada, CA 91011

ROBOTICS ASSOCIATIONS

British Robot Association
T.E. Brock, Executive Secretary
35-39 High Street
Kempston
Bedford MK42 7BT
ENGLAND

Association Francaise de Robotique Industrieele (AFRI)
J. Chabrol, Secretary General
60 Allee de la Foret
92360 Mendon de la Foret
FRANCE

Societa Italiana perla Robotics Industriale (SIRI)
c/o Professor M. Samalvico
Instituto di Elettrotechnica ed Elettronics
Politechmico di Milano
Piazza Leonardo da Vinci 32
20133 Milano
ITALY

Japan Industrial Robot Association (JIRA)
Mr. K. Yonemoto, Executive Director
Kikai Shinko Kaikan Building
3-5-8 Shiba-koen
Minato-ku
Tokyo 105
JAPAN

Robot Institute of America
Bernard Sallot, Executive Director
One SME Drive
P.O. Box 930
Dearborn, MI 48128

Robotics International of SME
One SME Drive
P.O. Box 930
Dearborn, MI 48128

ROBOT MANUFACTURERS

The American Robot Corporation
P.O. Box 10767
201 Miller Street
Winston-Salem, NC 27108
(919) 748-8761

Advanced Robotics Corporation
Newark Ohio Industrial Park
Building 8, Route 79
Hebron, Ohio 43025
(614) 929-1065

Armax Robotics Inc.
38700 Grand River Avenue
Farmington Hills, MI 48018
(313) 478-9330

ASEA Inc.
U.S. Headquarters
4 New King Street
White Plains, NY 10604
(914) 428-6000

Automation Corporation
Industrial Robots & Part
Handling Devices
23996 Freeway Park Drive
Farmington Hills, MI 48024
(313) 471-0554

Automatix Incorporated
217 Middlesex Turnpike
Burlington, MA 01803
(617) 273-4340

Binks Manufacturing Company
9201 W. Belmont Avenue
Franklin Park, IL 60131
(312) 671-3000

Cincinnati Milacron
Industrial Robot Division
Mason-Morrow Road
South Lebanon, OH 45036
(513) 494-5274

C. Itoh & Company, Inc.
21415 Civic Center Drive
Southfield, MI 48078
(313) 352-6570

Copperweld Robotics
1401 East Fourteen Mile Road
Troy, MI 48084
(313) 585-5972

Cybotech Corporation
P.O. Box 88514
Indianapolis, IN 46208
(317) 298-5890

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APPENDIX B

SELECTED GLOSSARY OF ROBOTICS TERMS

ACCURACY - The ability of the manipulator to position the end effector (tool or gripper) at a specified point in space upon receiving a command by the controller.

ACTUATOR - A transducer that converts electrical, hydraulic, or pneumatic energy to cause motion of the robot.

ARM - An interconnected series of mechanical links and joints that support and move the end effector through space.

ARTIFICIAL INTELLIGENCE - The ability of a machine to perform certain complex functions normally associated with human intelligence, such as judgement, pattern recognition, understanding, learning, planning, and problem solving.

BASE - The platform which supports the manipulator arm.

CLOSED LOOP CONTROL - Robot control which uses a feedback loop to measure and compare actual system performance with desired performance, and then makes adjustments accordingly.

COMPUTER-AIDED DESIGN (CAD) - The use of a computer to assist in the design of a product or manufacturing system.

COMPUTER NUMERICAL CONTROL (CNC) - The use of a dedicated computer within a numerical control unit that provides data input for the machine.

CONTACT SENSOR - A device that detects the presence of an object or measures the amount of force or torque applied by the object through physical contact with it.

CONTINUOUS PATH MOTION - A type of robot motion in which the entire path followed by the manipulator arm is programmed on a constant time base during teaching, so that every point along the path of motion is recorded for future playback.

CONTROLLER - The robot brain, which directs the motion of the end effector so that it is both positioned and oriented correctly in space over time.

CYCLE - One complete sequence of robot motions from the start of one operation to the start of another.

CYLINDRICAL COORDINATE ROBOT - A robot whose manipulator arm moves along a cyclindrical coordinate system so that the work envelope forms the outline of a cylinder.

DEGREES OF FREEDOM - The number of independent ways in which the end effector can move, defined by the number of rotational or translational axes through which motion can be achieved.

DIRECT NUMERICAL CONTROL (DNC) - The use of a computer for providing data inputs to several remote numerically controlled machine tools.

END EFFECTOR - The tool or gripper which is attached to the mounting surface of the manipulator wrist in order to perform the robot's task.

EXTERNAL SENSOR - A feedback device for detecting locations, orientations, forces, or shapes of objects outside of the robot's immediate environment.

FLEXIBILITY - The ability of a robot to perform a variety of different tasks.

FORCE SENSOR - A device that detects and measures the magnitude of the force exerted by an object upon contacting it.

GRIPPER - The hand of the manipulator, which is used by the robot to grasp objects.

GROUP TECHNOLOGY - The grouping of parts into categories having common characteristics, such as shape, so that all parts within each category can be processed together.

HARD AUTOMATION - Automated machinery that is fixed, or dedicated, to one particular manufacturing task throughout its life.

HIERARCHICAL CONTROL - A control technique in which the processes are arranged in a hierarchy according to priority.

HYDRAULIC MOTOR - An actuator which converts forces from high pressure hydraulic fluid into mechanical shaft rotation.

INTERFACE - A boundary between the robot and machines, transfer lines, or parts outside of its immediate environment. The robot must communicate with these items through input/output signals provided by sensors.

INTERLOCK - A safety device which prevents the robot from operating further until some condition has been satisfied.

INTERNAL SENSOR - A feedback device in the manipulator arm which provides data to the controller on the position of the arm.

JOINTED ARM ROBOT - A robot whose arm consists of two links connected by "elbow" and "shoulder" joints to provide three rotational motions. This robot most closely resembles the human arm.

LEADTHROUGH PROGRAMMING - A means of teaching a robot by leading it through the operating sequence with a control console or a hand-held control box.

LIMIT SWITCH - An electrical switch that is actuated when the limit of a certain motion is reached and the actuator causing the motion is deactivated.

LOAD CAPACITY - The maximum weight that can be handled by the robot without failure.

MANIPULATOR - The mechanical arm mechanism, consisting of a series of links and joints, which accomplishes the motion of an object through space.

MANUAL PROGRAMMING - A means of teaching a robot by physically presetting the cams on a rotating stepping drum, setting limit switches on the axes, arranging wires, or fitting air tubes.

MICROPROCESSOR - A compact element of a computer central processing unit constructed as a single integrated unit, and increasingly used as a control unit for robots.

NON-SERVO CONTROL - The control of a robot through the use of mechanical stops which permit motion between two end points.

NUMERICAL CONTROL (NC) - A means of providing prerecorded information that gives complete instructions for the operation of a machine.

OFF-LINE PROGRAMMING - A means of programming a robot by developing a set of instructions on an independent computer and then using the software to control the robot at a later time.

ON-LINE PROGRAMMING - A means of programming a robot on a computer that directly controls the robot. The programming is performed in real time.

OPEN LOOP CONTROL - A system of robot control that does not rely on a feedback loop for measuring performance. In open loop control, communication is in one direction only.

PAYLOAD - The maximum weight that can be handled by a robot during normal operation.

PICK AND PLACE ROBOT - A non-servo robot, which operates by moving along each axis between two end points. These robots are generally used for simple part transfer operations.

PITCH - Rotation of the end effector in a vertical plane around the end of the manipulator arm.

POINT-TO-POINT MOTION - A type of robot motion in which a limited number of points along a path of motion is specified by the controller, and the robot moves from point to point rather than in a continuous, smooth path.

PROGRAMMABLE - A feature of a robot that allows it to be instructed to perform a sequence of steps, and then to perform this sequence in a repetitive manner. It can then be reprogrammed to perform a different sequence of steps, if desired.

PROXIMITY SENSOR - A noncontact sensor which determines when one object is close to another.

RECTANGULAR COORDINATE ROBOT - A robot whose manipulator arm moves in linear motions along a set of cartesian, or rectangular axes. The work envelope forms the outline of a three dimensional rectangular figure.

RELIABILITY - The percentage of time during which the robot can be expected to be in normal operation (i.e., not out of service for repairs or maintenance). This is also known as the uptime of the robot.

REPEATABILITY - The ability of the manipulator arm to position the end effector at a particular location within a specified distance from its position during the previous cycle.

ROBOT - A reprogrammable multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motion for the performance of a variety of tasks.

ROLL - Rotation of the end effector in a plane perpendicular to the end of the manipulator arm.

ROTATIONAL MOTION - A degree of freedom that defines motion of rotation about an axis.

SENSOR - A feedback device which can detect certain characteristics of objects through some form of interaction with them.

SERVO CONTROL - The control of a robot through the use of a closed loop servo system, in which the position of a robot axis is measured by feedback devices and compared with a predetermined point stored in the controller's memory.

SHOULDER - The manipulator arm link joint that is attached to the base.

SPEED - The maximum speed at which the end of the manipulator arm can move at a certain load.

SPHERICAL COORDINATE ROBOT - A robot whose manipulator arm moves along a spherical coordinate system (radial motion plus two angles), so that the work envelope forms the outline of a sphere.

TACTILE SENSOR - A sensor that detects the presence of an object or measures force or torque through contact with the object.

TEACHING - The process of programming a robot to perform a desired sequence of tasks.

TOUCH SENSOR - A sensor that detects the presence of an object by coming into contact with it.

TRANSLATIONAL MOTION - Movement of a robot arm along one of three axes without rotation.

VISION SENSOR - A sensor that identifies the shape, location, orientation, or dimensions of an object through visual feedback, such as a television camera.

WALKTHROUGH PROGRAMMING - A method of programming a robot by physically moving the manipulator arm through a complete operating cycle. This is typically used for continuous path robots.

WORK ENVELOPE - The three dimensional space that defines the entire range of points which can be reached by the end effector.

WRIST - The manipulator arm joint to which an end effector is attached.

YAW - Rotation of the end effector in a horizontal plane around the end of the manipulator arm.

APPENDIX G

ROBOT REPORT REVIEWS

INDUSTRIAL ROBOTS

A SUMMARY AND FORECAST FOR MANUFACTURING MANAGERS

Ronald J. Sanderson
John A. Campbell
John D. Meyer

The most recent in a rapidly expanding series of publications is this special report prepared by Tech Tran Corporation. In 167 pages the authors introduce industrial robots, review robot characteristics, and define commonly used terms. Characteristics of 83 robots are tabulated which is a useful contribution. Unfortunately with the rapid introduction of new robots such a list can never be complete, e.g., the line of General Electric robots introduced at the Autofact show in November 1981 are not included. Services offered by each manufacturer are also tabulated.

The third section considers industrial applications and the fifth section discusses the selection and implementation of robots. These two chapters present data that a novice should find of value.

We found the most interesting section to be the discussion of future developments. One table presents current robot problems or needs as viewed by robot manufacturers, researchers, companies planning to use robots, and companies already using robots. The difference of views between these groups is interesting. The companies that are already using robots and the manufacturers see the situation about the same, while, researchers differ frequently with both groups. The companies planning to use robots see problems significantly different than the users, manufacturers, and even researchers. The lack of consistency demonstrated here indicates a problem the industry must resolve. Everyone appears to have their own view.

We also find forecasts of the technical future interesting. The authors estimate 260,000 industrial robots will be in use by 1991 and show an almost exponential growth with 160,000 robots added in the last 2 years of the period. This reviewer believes this is excessively high. Assuming that the average robot costs $100,000, this would represent an $8 billion annual manufacturing business which is about four times larger than seems reasonable to us. The authors have estimates of 1981 and anticipated 1991 robot applications.

This report is definitely worth obtaining and reading. Those already involved with robots will want to see what the authors project for the future. For those attempting to find out how robots will impact their operation, this is as good a place to start as any. Those involved in, or planning to get involved in, robot research should make a special point of reviewing this report so that their research attacks the problems users and manufacturers believe are important.

Copies of the report can be obtained from Tech Tran Corporation, 134 North Washington Street, Naperville Illinois 60540. The price is $50.00 in the United States, Canada, and Mexico, and $65.00 elsewhere.

BOOK REVIEW
INDUSTRIAL ROBOTS

The economic climate in the U.S., over the past two decades has presented them with rapidly increasing inflation, high energy costs, increased Government inflation and hazardous operations. This has resulted in a fall-back in necessary capital investment and in new technological advances. Thus in the years from 1973 through to 1979, productivity growth in the U.S. has been less than 1% per year - a major decrease from the 3% yearly average of the sixties. Productivity growth has been slowing down because of the changed attitudes of the direct labour personnel to perform monotonous and hazardous jobs. There has been, then, a decline in productivity growth but a sharp increase in labour costs.

It will be useful at this point if we define what we mean by an industrial robot, and this may be done by reviewing the various categories of manufacturing automation. Thus we would say with the author of the book under review that "automation ranges in degree from simply the use of powered or non-powered tools to the complete control of a task by a computer-aided manufacturing system involving high storage memories, sensory devices and periodic changes in programming". Within this definition we have the categories of "hard automation" and "Flexible automation".

In the context of hard automation, the task is performed by a tool which has been set up by using mechanical limits and adjustments thus making human beings completely redundant during operations. But because hard automation is dedicated to one application throughout the life of the tool there is, obviously, the difficulty of justifying the necessary investment.

Initially the alternative to hard automation was to increase substantially the labour content of any manufacturing task. It was necessary, therefore, to develop an automation system which would be sufficiently flexible to effect the increase in the range of tasks that could be performed together with an improved changeover capability of manufacturing tools.

It will be appreciated that initially the alternative to hard automation was to increase the direct labour content of a given manufacturing task. Now, however, flexible automation makes this unnecessary because of its improved changeover capability of manufacturing tools and the fact that the tool has not to be pre-programmed by a human being because of considerable flexibility and because in any case, changeover can be accomplished by reprogramming rather than replacing - or reworking - equipment.

When we talk about the robot it is policy to be able to define what it is specifically. We may call it a "reprogrammable multifunctional manipulation designed to move material parts, tools, and specialised devices through valuable programmes motion for the performance of a variety of tasks". It may be referred to as a "programmable manipulation with a number of articulations" or follow the Japanese Industrial Robot Association four-level definition:

- Manual manipulation that performs sequences of tasks which are fixed on present.
- Playbacks that repeat fixed instructions.
- Numerically controlled robots that carry out tasks through being numerically loading.
- Intelligent robots that perform through their own recognition capabilities.

It will be appreciated that industrial robots are obtainable in many configurations but they all nevertheless consist of three basic elements.

1. A Manipulator
2. A Controller.
3. A Power Supply.

Thus the robot has its basic element which is responsible for performing the work, its brain which directs the movement of the manipulator and its energy source.

Since an industrial robot has as its objectives its movement through three dimensional space, it requires its manipulator with its mechanical 'arm' and 'wrist'. These are mounted on a support stand. At the end of the wrist there is a mounting surface for attaching the end effects with which the robot performs its job and which is in the form of a gripping device for both grasping and manipulating any part.

As which will be appreciated there will be several alternative ways in which a manipulator can be so constructed as to move a part through space. The necessary motion may be achieved through a series of mechanical linkages and joints as in the human arm, and there are currently four different co-ordinate systems in use for moving a part from point 'A' to point 'B' the simplest being the rectangular, or cartesian co-ordinate system in which all motion is translational and moving straight along one of three perpendicular axis. Such type of motion is the easiest to control and is often used in the "pick and place" type of robot which we use for transporting parts from one point to another.

In most available robots arm configurations based upon rotational motion about several axis, are being used inspite of them being more difficult to control and which is because of their greater range and simpler design. What determines the potential use is the "work envelope" within which the robots and effects are capable of working. Thus one must appreciate the fact that a robot work envelope is very much like the human work envelope defined by engineers, and will naturally include drawings of work envelopes for each robot model, together with the relevant dimensions. Typical work envelope shapes are illustrated in the book together with their relevant uses.

What or who controls the system? It is the control unit, the brain of the robot' which is in command and its basic function is to so direct the motion of the end effects that it is positioned and oriented correctly in space over time. The Controller stores the necessary sequence of motions of the manipulator and end effects in a memory, and when requested by an operator directs the manipulator through the programmes sequence of motions, while at the same time it interacts with the manipulator and other machines connected with the robot through the feedback devices so as to ensure that the correct motions are being followed.

There are different kinds of robot controllers because robot control can be effected through the use of a stepping down programme, a pneumatic logic sequence, a diode matrix board, an electronic sequence, a microprocessor, or a minicomputer, and the controller may be integrated into the manipulator arm as it may be a separate unit.

The motion of the manipulator is controlled by feedback devices located on the arm links and the controller checks constantly the motion position, alternation speed, and acceleration of the end effects prior to directing it through its operating cycle.

The control unit or "Brain of the robot" functions so as to direct the motion of the end effects thus ensuring that the end effect is both positioned and oriented correctly in space over time. The required sequence of motions of the manipulator arm and effects are stored in a memory by the controller who, when requested by an operator, directs the manipulator through the programmes sequence of motions. In time with this, it interacts with the manipulator and other machines connected with the robot through various planned feedback devices to ensure that the correct motions are being followed.

It will be understood that a variety of robot controllers are available and such control may be accomplished through using a stepping down programme, a pneumatic logic sequence, an electronic sequence, a minicomputer and so on, and there are several categories of robot control, the most commonly employed being explained in some detail by the authors, such as Non-servo Robots, Point to point servo robots and Continuous path servo robots.

Thus we would say that "Non servo robots are controlled by directing each axis to move between two end points, using an open loop (home feedback) system". They use feedback devices to control the position of the axis at any point within its range and we have servo robots using feedback devices on the axis of the manipulator in order to measure and control the position of the axis at points within range.

The authors have dealt at some length with the industrial robot application. It will be very clear to the reader that automated machines can operate repetitively without any assistance from human beings. We are virtually redundant now in many manual situations. What will be the criteria for their use? Obviously in situations where capabilities are required which humans haven't got, where robots can perform much better than humans and where the safety hazards are such that humans would not be allowed to operate there in any case. Of course, the Authors of the Book deal very fully with commercial and industrial robot applications. Certainly the robot industry is booming and will undoubtedly continue to expand through the 1980's and 90's even without further improvement in robot capabilities, and we must expect both growth in the next few decades and further developments into areas not yet touched

How will governments get the support of its people to extend automation? Even if government get the commitment of management - and that is not necessarily assured - it will face considerable difficulties with the trade unions, and there will be difficulties when we have to integrate the robot into the existing production environment.

The authors have given us useful Appendices which deal with books, reports and publications which are relevant, together with ROBOTICS ASSOCIATIONS, and also provide us with a Glossary of Robotics Terms. At least, if we become unemployed through the introduction of the robots we may nevertheless order the relevant reading material through our local library, whoever and whatever is in charge.

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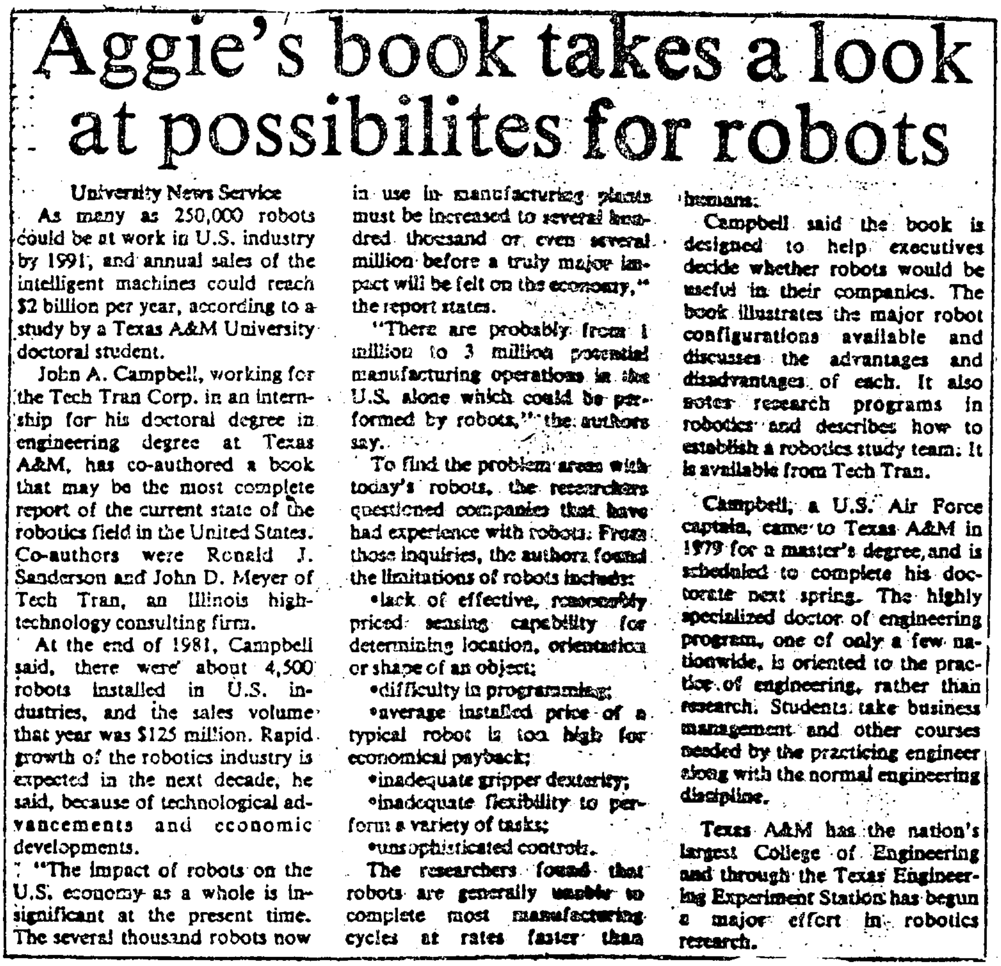

Aggie's book takes a look at possibilites for robots

University News Service

As many as 250,000 robots could be at work in U.S. industry by 1991, and annual sales of the intelligent machines could reach $2 billion per year, according to a study by a Texas A&M University doctoral student.

John A. Campbell, working for the Tech Tran Corp. in an internship for his doctoral degree in engineering degree at Texas A&M, has co-authored a book that may be the most complete report of the current state of the robotics field in the United States. Co-authors were Ronald J. Sanderson and John D. Meyer of Tech Tran, an Illinois high-technology consulting firm.

At the end of 1981, Campbell said, there were about 4,500 robots installed in U.S. industries, and the sales volume that year was $125 million. Rapid growth of the robotics industry is expected in the next decade, he said, because of technological advancements and economic developments.

"The impact of robots on the U.S. economy as a whole is insignificant at the present time. The several thousand robots now in use in manufacturing plants must be increased to several hundred thousand or even several million before a truly major impact will be felt on the economy," the report states.

"There are probably from 1 million to 3 million potential manufacturing operations in the U.S. alone which could be performed by robots," the authors say.

To find the problem areas with today's robots, the researchers questioned companies that have had experience with robots. From those inquiries, the authors found the limitations of robots include:

•lack of effective, reasonably priced sensing capability for determining location, orientation or shape of an object;

•difficulty in programming;

•average installed price of a typical robot is too high for economical payback;

•inadequate gripper dexterity;

•inadequate flexibility to perform a variety of tasks;

•unsophisticated controls.

The researchers found that robots are generally unable to complete most manufacturing cycles at rates faster than humans.

Campbell said the book is designed to help executives decide whether robots would be useful in their companies. The book illustrates the major robot configurations available and discusses the advantages and disadvantages of each. It also notes research programs in robotics and describes how to establish a robotics study team. It is available from Tech Tran.

Campbell, a U.S. Air Force captain, came to Texas A&M in 1979 for a master's degree, and is scheduled to complete his doctorate next spring. The highly specialized doctor of engineering program, one of only a few nationwide, is oriented to the practice of engineering, rather than research. Students take business management and other courses needed by the practicing engineer along with the normal engineering discipline.

Texas A&M has the nation's largest College of Engineering and through the Texas Engineering Experiment Station has begun a major effort in robotics research.

Bryan-College Station Eagle Newspaper, Saturday, July 31, 1982, Page 8A.

APPENDIX H

MICOM SUMMARIES

Prepared by: John Campbell

Date: 15 Feb 62

Project 3140 - Improved Manufacturing Processes for Silicon Target Vidicons

BACKGROUND: Silicon target vidicons are used in optical contrast terminal homing seekers and other rugged electro-optical devices. These devices, which are similar to a solid state TB tube, are produced using state-of-the-art manufacturing processes and both their quality and reliability are highly dependent upon this process. The yield rate of these devices has been typically less than 10 percent. There are only two companies having the technology and capability to produce these devices, and their capability is very limited as a result of the yield rate. New production techniques were needed to produce these items in quantity, increase yield rates and reduce production cost.

The principle components of a silicon target vidicon tube consist of a silicon target mounted inside either a glass or ceramic tube assembly. The silicon target is a very high cost component of the vidicon tube. The reason for its high cost is because it is mounted in the ceramic or glass tube and sealed prior to its first electrical test. Once the tube is sealed it is very difficult to rework for a defective silicon target. Because of this, extreme care is taken to assure that targets are not defective prior to mounting and sealing. This care is very expensive and still results in failures after electrical test. As the result of these problems and a requirement for a more ruggedized tube MICOM awarded a two year contract in June 1976.

OBJECTIVES: The objectives of this MM&T program were to increase the producibility, performance and yield, thus reducing the production cost of ruggedized silicon target vidicon assemblies used in optical contrast terminal homing seekers and other rugged electro-optical devices. This was to be accomplished by analyzing and solving production problems on a small scale preproduction level. The verification of the soundness of these solutions would be performed by demonstrating the capability of producing forty assemblies which meet the established technical requirements in a four-month time frame, using a standard 40 hour work week.

ACCOMPLISHMENTS: This MM&T project developed improved inspection and testing techniques which allowed electrical testing of silicon targets prior to mounting in the ceramic tube. This results in considerable less value being added to the vidicon tube by identifying and discarding defective devices prior to mounting. Several other areas were investigated and resulted in increased producibility and yield rates for the silicon vidicon tube assemblies. New more effective methods and materials were developed for uniformally bonding the silicon targets to its face place. Several anti-reflective coating materials used on the silicon targets were evaluated an an optimum coating thickness developed. Because of the lack of availability, a new potting material was developed and several jigs and fixtures were fabricated which allowed easier assembly, test and inspection of the silicon vidicon assemblies. Because of these and other improvements in the manufacturing process, the contractor was able to demonstrate an 80% yield for the silicon targets and an overall tube yield of 43%. This was a significant improvement over the yield rate of the original manufacturing process.

Todate very few silicon vidicon tubes manufactured using the MM&T project results hae been installed on military programs. There are two main reasons for not using this tube. First, even during the MM&T program, several contractors requested a device that had much more cpabilities than the one demonstrated during the project. In order to memet these new requirements, the yield would be greatly affected and the cost increased. Secondly the decrease in yield and increase in cost has made it much more difficult to acquire and justify this tube over other technologies and manufacturers. However, these other tube technologies do not appear to be as rugged as the one developed under this MM&T project.

There appears to be a need for a follow-on MM&T project in this area to again increase the yield and reduce the cost of a rugged silicon vidicon tube. New military programs with increased requirements for this technology has produced a need for a low cost, rugged silicon vidicon tube.

BENEFITS: This program was successful in improving the producibility, performance and yield of rugged silicon vidicon tubes. It is recognized as the most ruggedized tube manufactured today. Because of this ruggedness, it has been proposed to be used on many military systems including Army, Navy, Air Force and Marine programs. It was originally designed for the HELLFIRE program but never incorporated. It has been evaluated for use on several Army programs including Advanced Attack Helicopter (AAH), Army's Helicopter Improvement Plan (AHIP), and Target Acquisition Display System (TADS), and Pilots Night Vision system (PNVS). It was used by Westinghouse Corporation as instrumentation to evaluate the performance of the M-60 and XM-1 tanks. This tube is also being used by Northrop Corp on the Navy's SEAFIRE program for shipboard daytime fire control. There is a potential of 200-300 units installed on this program. Northrup is presently preparing a bid to use this tube on an US Air Force search and rescue program designated as the HX program. There is a possibility of 250 units being used on this helicopter program. Most recently, this technology is being investigated for use on a US Marine Program called the Mobile Protected Weapon System (MPWS) and a US Army program called the Mobile Protected Gun System (MPGS). These programs have requirements for an extremely rugged vision system. No quantities have been identified for these programs.

MICOM MM&T PROJECT 3140

IMPROVED MANUFACTURING PROCESSES FOR SILICON TARGET VIDICONS

INTERVIEW LIST

Name	Organization	Telephone Number
Doug E. Crosswhite	MICOM	(205) 876-2147
Joe Aranson	RCA	(617) 272-4000 X 3341
Donald C. Reed	RCA	(717) 397-7661 X 3691
Don Maruoka	Northrop Corp.	(714) 871-5000 X 1262
Jim Meachem	Westinghouse Corp.	(301) 765-2316
Don Ekins	Northrop Corp.	(714) 871-5000 X 231

EFFECTIVENESS REPORT
(RCS DRCMT-303)

1. Project No. 3140 Subtask No. ______ 2. Command MICOM

3. Funding FY's 76,7T, 78 4. Title Improved Manufacturing Processes for Silicon

5. Project Engineer E. Crosswhite 6. AUTOVON 746-2922

7. Implementation Status (Check One):

IMPLEMENTATION	Previous Survey
X Implementation Completed (XM-1 TM60)	______
X Implementation In-Process(SEAFIRE)	______
X Implementation Planned (HX, MPGS, MPWS)	______
______ Available for Implementation	______

NON-IMPLEMENTATION

______ Effort Continued Under Another Project
______ Not Economically Feasible
______ Requirements Changed
______ Unsuccessful Project

8. Tech Transfer Media:

X Tech Report
______ Handbook Distribution
______ Technical Article Publication
______ Technical Presentation
______ Government Demonstration
______ Government/Industry Demonstration

9. Tech Transfer Comment (When, Where, How):
Final technical report distributed and sample hardware available on request.

10. Implementation Comment:
This technology is being used on the Navy's SEAFIRE system by Northrup. It was used by Westinghouse as instrumentation on the XM-1 and M60 tank test program. Northrup has proposed to use it on an Air Force program (HX) for search and rescue and it is being evaluated for an Army and Marine program called MPGS and MPWS respectively.

11. Status of This Implementation: X Actual X In-Process X Planned ____ Available

a. Implementation Method (Check One):

Government Facility

______ Self-Implementing
______ Government Facilitization
______ Directive
______ Specification Change
______ Other Government Agency Initiative
______ Other (Specify Below)

Contractors Facility

______ Self-Implementing
______ Contractual Language
______ Government Furnished Equipment
X Contractor Initiative
______ Specification Change
______ Other (Specify Below)

DRXIB Form 72, 1 Dec 79

EFFECTIVENESS REPORT (Cont'd)

b. End Items/Components Supported: XM-1, M60, SEAFIRE, HX, MPGS, MPWS

c. Type Facility: _____ GOGO _____ GOCO X COCO

d. Location (City & State): (SEAFIRE) Anaheim, CA

e. Actual or Planned Implementation Date: 1980

f. Government Facility or Contractor Name: Northrop

g. Contract Number: N60921-79-C-A198

h. Implementation Cost: FYDP _____ MOB _____

i. Savings: FYDP _____ MOB _____

j. Manufacturing Processes, Techniques or Methods Supported by This Implementation:

Ruggedized vidicon tube

k. Benefits of Implementing MMT Results (Rank in order of significance, limit to three benefits):

_____ Cost Reduction
_____ Standardization
_____ Ability to Produce
_____ Lead Time Reduction
_____ Pollution Abatement
2 Improved Readiness
1 Improved Product Quality/Reliability
_____ Improved Material
_____ Sole Source Elimination
_____ Energy Conservation
_____ Safety/Health Improvement
_____ Improved Mfg Equip Reliability/Availability

TABLE 1

Savings Year	Annual Savings*		Discount Factor	Discounted Savings	
	FYDP	MOB		FYDP	MOB
1			0.954		
2			0.867		
3			0.788		
4			0.717		
5			0.652		
6			0.592		
7			0.538		
8			0.489		
9			0.445		
10			0.405		

Total Discounted Savings - _____
Initial Savings Year - 19__

*If actual data is not available, provide estimated values (in parenthesis)

Project 3140-OCR

PROJECT SUMMARY: Silicon target vidicons are similar to solid state TV tubes and are used in optical contrast terminal homing seekers and other electro-optical devices. These devices are manufactured using state-of-the-art production techniques and have dry poor reliability and yields. This project increased the producibility, performance and yield of a more ruggedized silicon target vidicons. Improved inspection and testing techniques were developed which allowed electrical testing of the silicon targets prior to mounting in the tube. This allows identifying and discarding defective devices prior to mounting in the tube and thereby reducing cost significantly. Several materials and processes used in fabricating these devices were optimized such that the yield rates of the silicon targets went from 10 percent to 80 percent and the overall tube yield increased to 43 percent. It is recognized that this MM&T project produced the most ruggedized tube manufactured today. It is presently being tested on the Navy's SEAFIRE program and was used to evaluate the M-60 and XM-1 tanks. It was evaluated for use on several Army programs including the HELLFIRE, AAH, AHIP, TADS and PNVS. It is presently being evaluated for use on the Air Force's HX program for search and rescue, the Army's Mobile Protected Gun System, and the Marine's Mobile Protected Weapon System.

PROBLEM STATEMENT: Silicon target vidicons used in optical contract terminal homing seekers are very expensive and have typical yield rates of around 10 percent. Presently, there is no way of checking the critical silicon target prior to assembly.

SOLUTION STATEMENT: Increased producibility, performance and yields of silicon target vidicons resulted from evaluating their manufacturing methods, materials and processes. Test methods were improved to allow testing of silicon target prior to assembly.

Prepared by: John Campbell
Date: 24 March 82

Project 3219 - Automated Hybrid DIE Attach Machine

BACKGROUND: The use of hybrid microelectronic circuit assemblies for missile electronic systems provide significant advantages in smaller volume and lighter weight. These devices are typically assembled by hand and because of the advantages listed above are being used more frequently in military systems. The average cost of a hybrid microelectronic assembly is approximately $250 per unit, a large part of which is labor cost. The current trend throughout the Military Hybrid Industry is reduction of operator controlled variables in an effort to reduce cost and increase reliability while maintaining or increasing equipment volume handling capability. An important area in which this can be accomplished is in the chip to substrate assembly operation. However, this process has been very difficult to automate because of the small size of the chips, the variation in dimensions, and the accuracies required to position them onto the substrate. But with the recent increase advances in flexible programmable automated equipment, automated recognition and control systems and other very accurate programmable positioning systems, it has become feasible to automate this process. Therefore, because the technology is now available and recognizing a need to reduce the cost of hybrid microelectronic devices, MICOM awarded a 12 month contract to develop an automated hybrid die bonding system.

OBJECTIVES: The objective of this project is to reduce the cost of manufacturing hybrid microelectronic assemblies. This is to be accomplished in two parts. First, to be accomplished under this project, is to design and develop using as much existing technology as possible an automatic chip recognition die bonding system. This system would use a robotic arm, a TV monitoring and control system, chip dispensing equipment, and substrate positioning and transferring equipment. The next phase of this project will be to finalize the design, fabricate a prototype machine, and then test and demonstrate the machine using several different hybrid package designs.

ACCOMPLISHMENTS: An automated machine used in the assembly of hybrid microelectronic circuits has been defined and a preliminary design has been specified. The microelectronic industry was surveyed to identify what were the types of microelectronic devices being manufactured, what were the types of die bonding equipment presently available, and what type of equipment would be required to automate this process. This survey identified hybrid process parameters, typical package dimensions, typical components, production rates, assembly cycle times, etc.

The machine specified will be an integrated computer based system capable of assembling all dies correctly oriented on a single substrate, and then automatically exchange substrates. The equipment will be a robot based system which will be capable of handling over 25 different semiconductor devices and ten (10) different passive components. An integral part of this system will be a pattern recognition vision and control system that will allow the dies to be picked up without prearranging them. Finally substrate work holders and feeders, similar to existing equipment, will be integrated into the system.

BENEFITS: This project will facilitate the fabrication of a completely automated hybrid die bonding system. Automating this process will produce several benefits to the hybrid production process. First, significant cost savings will result by reducing the labor content in the manufacturing process. Also reducing the amount of human contact in this assembly process will significantly increase quality, reliability, and yield of these devices. Production rates will increase thereby reducing leadtimes for these devices.

Several other indirect benefits will result with the use of this machine. Wire bonding times will be reduced because of the accurate positioning required by this machine and batch processing of several hybrid package sizes can be performed automatically. This machine and several less sophisticated models will be marketed commercially based on the technology developed under this MM&T project.

Project 3219 - Automated Hybrid DIE Attach Machine

PROJECT SUMMARY: Hybrid microelectronic circuit assemblies are being used more frequently in missile system because of the advantages of less weight and volume. The average cost of a hybrid is approximately $250 per unit and is almost entirely hand assembled. Recent technological increases in flexible programmable automated equipment, automated recognition and control systems and other very accurate programmable positioning systems have made it possible to introduce automation to this process. One area which has been identified for automation is the chip to substrate assembly operation. Therefore a preliminary design has been developed for a machine to automate this process. This machine will be an integrated computer based system using robotics and a pattern recognition vision and control system. The system will handle over 25 different semiconductor devices and ten (10) different passive components. The system will have the capability of picking up these dies without having them prearranged and placing them accurately onto the substrate. Significant cost will be reduced in manufacturing hybrid devices. Additionally, increases in quality, reliability, yield, and production rates are expected. This preliminary design shall be finalized and a prototype machine will be fabricated and demonstrated by Project 1976.

PROBLEM STATEMENT: Hybrid microelectronic devices are typically hand assembled with an average cost of approximately $250 each. Automating this assembly process is difficult because of chip sizes and positional accuracies required.

SOLUTION STATEMENT: An automated pattern recognition vision system interfacing with a programmable robot and other computer controlled positioning equipment has been designed to automate the hybrid die bonding process.

APPENDIX I

MICOM PROJECT EVALUATION

John A. Campbell
28 APR 82

MICOM EVALUATIONS

3140 - Improved Manufacturing Process for Silicon Vidicons

This project developed a more ruggedized tube but not any cheaper than other tubes. It's been used on a couple test programs and may be implemented in the future, but I doubt it because of cost.

3272 - Flex Circuits with Integral Molded Connectors

This project was one of the best and has applications to all services. It is the type of technology that should be required on electronic units where applicable.

3147 - Semi-Additive Process for Printed Circuit Boards

Presently this technology is more expensive than the substractive process, however, increased circuit density may require this technology in the future. This process is probably being used by many hybrid circuit manufacturers but cost benefit data would be difficult to document.

3167 - Controls to Prevent Plated-Through-Hole Cracking

Good project with significant impact in cost and reliability for Hi-Rel MLB's. I was unable to document cost saving but those techniques were implemented by several Aerospace companies. This would be a good project to follow-up.

3112 - Manufacturing Multilayer Rigid-Flex Harnesses

Excellent project with identifiable cost saving for Army, Navy and Air Force programs. Significant increase in reliability and probably should be specified by the government.

3219 - Automated Hybrid DIE Attach Machine

This will be a project to watch. The second phase is project 1076 which will build a prototype machine using a robot. However, I think it will have limited application because of hybrid diversity and quantities used.

3225 - Methods for Mounting Non-Axial Lead Components

Unsuccessful project because project was based upon a locator-insertion aid which produced component failures in high vibration environments. Might have commercial applications for inserting TO cans but I think quantities in use are too small for automating.

3009 - Methods of Manufacturing Electronic Modules

This was an old project (FY71) that probably layed the groundwork for today's electronic designs. It identified the need for more N.C. insertion and PWB designs. Any military system that changed from cordwood to PWBs benefited from this project. Estimate saving for TOW and Dragon missiles available.

3150 - Methodology for UV Cured Conformal Coating

Project was unsuccessful in developing a UV cured conformal coating material that was acceptable for military use. However, this material is in use on commercial PWBs and is still being looked at by Hughes.

2959 - Adaptation of Printed Circuit Tubelet Concept for Electronic Modules

This is a thirteen year old project that looked at cordwood technology. It identified much reliability and aging data but cost saving data would be difficult to document.

2993 - Manufacturing Techniques for Ferrites and Garnets Used in Phased-Array Radar

This process was never implemented on military hardware. No spin-off was identified.

3070 - NDT Methods for Small Composite Rocket Motor Components

This project is similar to project 3454 in that it used radiographic inspection. However, it also used ultrasonics to inspect some items. These two processes have not been implemented together, but radiographic systems are being developed and used. The radiographic process was used on another MM&T project which has potential of both large quantities and saving; "Low Cost Paper Motor Components." May pay to keep an eye on this for future benefits.

3454 - Low Cost High Volume Radiographic Inspection

This project was directed to the Roland Missile but may have spin-offs with significant savings. Non-Film X-Ray inspection will be the method of the future. A system is being implemented on the MLRS and the Air Force is further developing this technique for the ALCM. If MLRS can be related to this effort, then significant savings could be documented.

3012 - Production of Plastic Quadrant Missile Airframes

This project was never implemented and no spin-offs identified.

2967 - Transfer Molding Techniques for Encapsulation of Encapsulation of Electronic Modules

Another very old project that looked at potting cordwood modules. Cost saving would be difficult to document, but the process was used on thousands of modules.

3005 - Production and Inspection Techniques for Infrared Components

This is a thirteen year old project that would be difficult to document cost saving. However, standards were developed which helped future design efforts and follow-on development effort Have been undertaken by other Government agencies.

3036 - Manufacturing Process for Glass Fibers

The processes developed have not been implemented on a military system. There may have been spin-offs but I could not identify them.

3253 - High Current Density Cathodes

This project was a state-of-the-art development effort that did not produce acceptable devices until after the contract was finished. More R&D work is still required.

3116 - Rosette Air Defense Seeker Optics and Detector

This effort improved several manufacturing processes for the seeker and estimated potential cost saving of approximately $150/unit. They expect over 30,000 units to be manufactured beginning around 1983. Other missile systems are assessing some of the improved processes.

APPENDIX J

MICOM PROJECT RANKING

MICOM PROJECT EVALUATION - RANKING

Excellent

3272 - Flex Circuits with Integral Molded Connectors
3112 - Multilayer Rigid-Flex Harness
3116 - Rosette Air Defense Seeker Optics and Detector

Good

3167 - Controls to Prevent Plated-Through-Hole Cracking
3009 - Methods of Manufacturing Electronic Modules
3454 - Low Cost-High Volume Radiographic Inspection

Fair

3140 - Improved Manufacturing Process for Silicon Vidicon
3147 - Semi-Additive Process for Printed Wiring Boards
3219 - Automatic Polymer Attachment Production Methods
3070 - NDT of Rocket Motors
3005 - Production & Inspection Techniques for IR Components

Poor

3225 - Methods for Mounting Non-Axial Lead Components
2959 - Adaptation of Printed Circuit Tublet Concept for Electronic Modules
3150 - U.V. Cured Conformal Coating
3012 - Production of Plastic Quadrant Missile Airframes
2967 - Transfer Molding Techniques for Encapsulation of Electronic Modules
3036 - Manufacturing Process for Glass Fibers
3253 - High Current Density Cathodes
2993 - Microwave Ferrites and Garnets

APPENDIX K

MANUFACTURING TECHNOLOGY HORIZONS ARTICLES

JANUARY/FEBRUARY 1982
Volume 1, Number 1

manufacturing technology HORIZONS

THE DIGEST OF MAJOR DEVELOPMENTS IN MANUFACTURING PROCESSES AND EQUIPMENT

CONTENTS

FEATURES

MACHINING

TOOL WEAR SENSING

Engineers at the National Bureau of Standards have developed an inexpensive system for dynamically monitoring tool wear on numerically controlled machining centers. The system uses an accelerometer, microprocessor and special computer software to sense and analyze changes in vibrations caused by tool wear. A time-domain sampling and comparison algorithm which is synchronized to the drilling speed decreases the complexity inherent in similar approaches utilizing fast fourier transform techniques. Initial testing of the system has proven successful in eliminating workpiece damage caused by tool breakage and in predicting when actual breakage will occur. Hardware for implementation of the system can be purchased for about $500.

The current system is limited to constant rate drilling using small diameter drill bits. Further development efforts in variable drilling speeds, larger bit sizes, and non-magnetic attachment of the sensor to the workpiece are underway. Also, the concept is being adapted to numerically controlled milling machines.

For more information, contact: Mr. Donald Blomquist, National Bureau of Standards, Washington, DC 20234 (telephone: 301/921-3381). 82-001

NON-ROUND TURNING

Giddings and Lewis has recently developed a means to allow three-axis machining on a two-axis lathe. Originally developed for cutting non-helical threads, the technique permits computer numerical control of multiple axes so that non-circular motions can be made accurately within one-tenth of a degree of workpiece rotation. The techniques can be used for cutting eccentric grooves, non-circular trepanning and the preparation of saddle-shaped contours needed for T-joints in cylindrical stock and pipes.

The development represents a significant increase in the flexibility and capability of lathes and should see widespread use in many industries, including chemical and nuclear equipment and aerospace.

For more information, contact: Richard Werdin, Giddings & Lewis Machine Tool Co., 142 Doty Street, Fond du Lac, Wisconsin 54935 (telephone: 414/921-9400). 82-002

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ADVANCED MACHINING RESEARCH

The U.S. Defense Advanced Research Projects Agency is in its third year of a 4-year program to develop a science base for faster metal removal. Referred to as the Advanced Machining Research Program, the work is being managed by the U.S. Air Force and performed by a team of manufacturers, consultants, research institutes and universities under the leadership of General Electric. The research includes in-depth studies of high speed machining and laser-assisted machining, along with assessments of other innovative 'tooling and advanced machining concepts. The long term goal of the program is to provide significantly lower metal removal costs. Several noteworthy developments have emerged from the program thus far.

A new tool insert geometry, called the ledge tool, has been developed which offers up to five-fold increases in cutting speed and overall cost reductions ranging from 25 to 70% for machining titanium and aluminum alloys. The ledge tool has a geometry which allows a tool insert to wear without impairing its cutting ability. The "ledge" is formed by grinding square cemented carbide inserts to form an overhang equal to the depth of cut desired and a thickness equal to the flank wear that can be tolerated. During machining, the ledge wears progressively across the entire face of the insert, thereby extending tool life. Semi-finishing cuts in face milling appear to be the most cost-effective application of this tooling concept.

The program has also resulted in the development of a pneumatic in-process inspection system which uses an air probe proximity sensor to measure tool wear and workpiece dimensions during machining. The system is accurate to .02 mils over a 10.0 mil gap range and is the first attempt to utilize an air gauge backpressure measurement system for this application. The system is simple, reliable and inexpensive, and should be suitable for use in adaptive control systems.

In the area of laser-assisted machining, results from the program have shown that significant increases in metal removal rates can be achieved, but that from a cost standpoint the process usually cannot be economically justified due to high capital investment and low power absorption by the workpiece. Current studies indicate, however, that in some cases the use of low power CO_2 and Nd-YAG pulse lasers may be economically feasible for laser-assisted machining applications.

One of the most important results from the Advanced Machining Research Program has been and will continue to be the establishment of a better scientific understanding of machining processes, particularly with regard to chip formation and structure and analytical modeling techniques.

For more information, contact: Ms. Rosann Stach, Air Force Wright Aeronautical Laboratories, Attn: AFWAL/MLTM, Wright Patterson AFB, Ohio 45433 (telephone: 513/255-2413) or Dr. D. G. Flom, General Electric Company, Corporate Research and Development, P.O. Box 8, Schenectady, New York 12301 (telephone: 518/385-8179). 82-003

MACHINE ERROR COMPENSATION

The National Bureau of Standards is currently developing a technique to measure and compensate for 21 types of static machine tool errors to improve positional and machining accuracy. Errors from such sources as irregular leadscrews and spindle runout are measured for the machine tool, and the data is fed to a minicomputer for calculation of the combined positioning error throughout the entire work volume by means of vector mathematics. The minicomputer is then used to prepare numerically controlled part programs which compensate for the positioning errors. Development work is being done on a Brown & Sharpe 1500 VC vertical machining center with a General Electric 1050 controller. One of the first demonstration parts will be a cylinder requiring a positional accuracy of 2 micrometers over a length of 1 meter.

The new technique has the potential to increase machine positioning accuracy by a factor of five. With further development work, the system could be implemented on a microcomputer. A direct interface between the minicomputer and the machine controller would also require additional effort. Other research at NBS is directed at measurement and compensation of thermally induced errors and dynamic errors caused by tool wear and machine vibration.

For more information, contact: Mr. Thomas Charleton, National Bureau of Standard, Washington, D.C. 20234 (telephone: 301/921-2216). 82-004

FORMING

PROGRAMMABLE METAL FORMING DIES

Researchers at Massachusetts Institute of Technology have been investigating the feasibility of automated sheet metal forming using programmable dies. Referred to as the Flexible Die System, the concept employs an array of "pins" whose positions can be individually varied, thereby forming a non-continuous die surface. Although non-continuous die surfaces have been tried before, the key to MIT's approach is integration of the programmable die pins into an adaptively controlled forming system. In such a system, a designer would use a computerized data base to define the part to be fabricated. This information is then be used to program the required die surface. After the part is formed, its dimensions are automatically measured and any errors in shape are fed back to the computer program to modify the die surface. Iterations of the process continue until the formed parts meet specifications.

Although the entire process has not been automated, MIT's preliminary efforts have verifed the technical feasibility of the concept. Several test parts have been fabricated from 1/16 inch 3003-H14 aluminum. Using a prototype computer program, only a few iterations were required to achieve the correct die surface and part shape. Future work is still needed to refine the system and expand its capabilities. Although commercialization of the system is at least several years away, its major benefits would be in die design and prototyping and economical production of small quantities of formed parts.

For more information, contact: Dr. David Hardt, Department of Mechanical Engineering, Room 35-006, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139 (telephone: 617/253-2252). 82-005

COMPUTER ASSISTED THREE-ROLL BENDING

The Massachusetts Institute of Technology has recently demonstrated the feasibility of adaptively controlled three-roll bending. The system takes into account actual material properties, rather than nominal values, during the process and can reduce errors in final shape to about 3%. Referred to as Material Adaptive Control, the computerized system measures workpiece forces and displacements during forming and makes allowances for springback in the finished part. Although still in the early developmental stage, the new process could eventually lead to higher yields and closer tolerance rolling and straightening.

For more information, contact: Dr. David Hardt, Department of Mechanical Engineering, Room 35-006, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139 (telephone: 617/253-2252). 82-006

WELDING

PULSED MAGNETIC WELDING

A novel approach to welding, using magnetic force rather than heat, has been developed by Maxwell Laboratories. Workpieces are welded using the force created by a pulsed magnetic field of extremely high intensity. The magnetic field creates a force greater than 100,000 psi between the parts being joined and the resulting impact is great enough to cause a true metallurgical weld.

The basic advantage of pulsed-magnetic welding is that no heat is applied to the workpiece, therefore no melting occurs and crystallographic structure remains unchanged. The process also has potental for joining of dissimilar metals, such as nickel base alloys and stainless steels. It may even be possible to join such unlikely combinations as aluminum and stainless steel, although more development in this area is needed. Studies to date have concentrated on circular workpieces but application to other geometries is anticipated.

For further information, contact: Dr. Tom Olson or Mike Plum, Maxwell Laboratories, 8833 Balboa Avenue, San Diego, California 92123 (telephone: 714/279-5100). 82-007

FINISHING AND COATING

NEW GALVANIZING ALLOY

The Centre de Recherches Metallurgiques (Liege, Belgium), under the sponsorship of the International Lead Zinc Research Organization, has developed a new galvanizing alloy which should see widespread use by coated steel producers throughout the world. The new material, called GALFAN, is a Zn - 5% AL -

mischmetal alloy system based on earlier work performed by Inland Steel.

Trial production runs conducted by Ziegler S. A. (Mouzon, France) have demonstrated that CALFAN provides superior corrosion resistance, exceptional formability and fewer surface defects when compared to conventional galvanizing. Additional advantages include minimal capital investment costs for conversion of standard Sendzimir or Heurtsy type continuous galvanizing lines and reduced energy costs due to GALFAN's lower melting point. Full-scale commercial evaluations are expected in the near future.

For more information, contact: Mr. William Zeck, International Lead Zinc Research Organization, Inc., 292 Madison Avenue, New York, New York 10017 (telephone: 212/532-2373). 82-008

ARCSPRAYING

Based on a one year study, TAFA Metallisation has established that a thin copper coating on stainless steel wire provides improved arcspray metallizing. The copper coating lessens the voltage drop at the current transfer point between the wire and the contact tip, thereby reducing tip wear and erosion. The coating also provides smoother wire feeding, a quieter arc, more consistent spray quality and better directional control. 1/16 inch 13% chrome stainless steel wire with a flash coating of copper and special lubricant was used during the study.

The firm is also working on a novel application of arcspraying to produce corrosion-resistant anti-skid coatings of pure aluminum metal. Unlike conventional coatings composed of a paint vehicle and abrasive particles, the solid aluminum coatings do not require annual maintenance even in severely corrosive atmospheres. Tests conducted by the U.S. Navy on helicopter decks have logged five years at sea without deterioration. The new coating method employs a specially designed gun which electrically atomizes aluminum wire and produces a cool spray of 100% metal. In coating steel, a thin (5-7 mils), dense coat of aluminum is applied first as a corrosion protectant. A second anti-skid coat (20-40 mils) is then added. If the coating is being applied to aluminum structures, only the anti-skid coat is needed. The coatings can be applied at a rate of 95 square feet per hour. Both ease of application and economics compare favorably with epoxy and abrasive grain methods.

For more information, contact: M. A. Stickney, TAFA Metallisation INC., Dow Road, P.O. Box 1157, Bow (Concord), New Hampshire 03301 (telephone: 603/224-9585). 82-009

FOUNDRY PROCESSES

DUCTILE IRON INOCULATION

IIT Research Institute is pursuing a new approach for producing ductile iron. Rather than inoculating molten iron with magnesium by conventional techniques, they are investigating the in-ladle generation of magnesium by reacting burnt dolomite with high purity aluminum. The aluminum reduces magnesium oxide in the burnt dolomite to elemental magnesium, which subsequently acts as nucleation sites for the formation of nodular graphite. Limited feasibility studies have shown that the procedure does indeed result in cast iron with the desired nodular structure.

Potential benefits from the new process include a $30/ton reduction in inoculation material costs and elimination of silicon buildup arising from recycling gates and runners. Several key issues, however, still remain to be investigated. For example, the new process requires a ladle temperature about 250°F higher than conventional procedures. Thus, energy and refractory material consumption may be higher. Also, behavior and effects of the aluminum oxide formed during the reaction is not yet known.

For more information, contact: Mr. Bill Altergott, IIT Research Institute, 10 West 35th Street, Chicago, Illinois 60616 (telephone: 312/567-4179). 82-010

COMPUTER-AIDED MOLD DESIGN AND SIMULATION

A computer program for mold design and simulation of casting processes is being developed for the U.S. Army by the University of Pittsburg. Battelle, Blaw Knox and Lebanon Steel are also participating in the project. The program allows a designer to evaluate several alternative casting and mold configurations before committing to an actual prototype. Using a remote terminal, the designer specifies the casting's geometry and mold characteristics, such as risers, gating and parting lines. The computer program then automatically simulates the casting process using fluid flow models and finite element thermal analysis techniques. Outputs include time-varying solidification patterns and temperature contours and gradients which can be used to optimize the casting process and product design. The prototype software has been used to design steel castings made by green sand molding. Additional work is planned to expand the program's capabilities to handle more complex casting designs. Although other metals and casting processes could be simulated, it would require some software modification.

Use of the computer program should result in better quality castings, reduced production leadtimes and reduced costs for labor and material. Wide-scale availability of the computer program is at least several years away. Major obstacles to commercialization, however, are software maintenance and user support after development is completed.

For more information, contact: Mr. Michael Holly, U.S. Army Tank-Automotive Command, Attn: DRSTA-RCKM, Warren, Michigan 48090 (telephone: 313/574-5814) or Dr. Harold Brody, University of Pittsburg, 848 Benedum Hall, Pittsburgh, Pennsylvania 15261 (telephone: 412/624-5299). 82-011

POWDER METALLURGY

METAL INJECTION MOLDING

Witec California has developed and commercialized a process for injection molding high strength, precision metal parts. During the first stage of a three-stage process, a blend of micron-size metal particles combined with a proprietary plasticizer are injection molded at 5000 psi into a mold pre-heated to 100°F. The resulting preforms, which are about 20% larger than the final part, are subjected to the next processing stage: a 400°F low-temperature sintering that removes the plasticizer. During the last stage, the parts undergo a 2300°F baking cycle in a controlled gas atmosphere. The final parts achieve metal density of about 95%, are fully annealed, and require no additional machining. Metals that have been processed using this technique include mild steel, monel, stainless steel and a proprietary alloy that results in ultimate tensile strengths of over 200 ksi.

The long-term potential for this technology is impressive. Major benefits include a drastic cost reduction over machined parts and almost no material loss (gates and runners can be recycled). The company is also working on injection molding of ceramics.

For more information, contact: Allen Roshorn, Witec California, Inc., 4898 Ronson Court, San Diego, California 92111 (telephone: 714/268-3681). 82-012

PROGRAMMABLE DIES FOR POWDER METAL PARTS

Researchers at Carnegie-Mellon University have devised a programmable, plunger-type die for producing a variety of contours in P/M parts. The female component of the die contains a square array of moveable plungers whose vertical postions can be adjusted individually. Metal powder is deposited in the cavity and a male plunger applies the forming load. Components have been produced with square and T-shaped configurations with a number of step sizes. Sintered strength and other physical properties of the parts are equivalent to those made by conventional die pressing. The major difficulty with the concept has been in achieving curved surfaces. The individual plunger dimensions (.25 inches by .25 inches) have not provided sufficient surface resolution, and ongoing work is focused on alleviating this problem.

Though not complete, the work has established the technical feasibility of utilizing programmable die surfaces in powder metal processing. Future developments may involve the use of "families" of plungers, plungers having curved faces, and additional banks of plungers oriented in other planes. Once established, the technology would reduce tooling costs and set-up times and would allow economical production of small quantities of P/M parts.

For more information, contact: Dr. Paul K. Wright, Department of Mechanical Engineering, Carnegie-Mellon University, Pittsburgh, Pennsylvania 15213 (telephone: 412/578-3529). 82-013

RECYCLING AND WASTE PROCESSING

HOT PRESSING OF SCRAP

IIT Research Institute has shown the feasibility of producing metal parts by hot pressing scrap from machining operations. Scrap swarf of 2014 aluminum alloy was degreased and charged into a hot die at 850°F then subjected to a pressure of 40,000 psi for five seconds. Parts formed in this fashion and subsequently solutionized and aged to the T6 condition achieved 100 percent density and 80 percent strength as compared with wrought parts of the same material. Because of the potential for cost reduction and increased material utilization, this technique should be of value to almost any manufacturer who generates a great deal of scrap, particularly aluminum.

For additional information, contact: S. Rajagopal, IIT Research Institute, 10 W. 35th St., Chicago, Illinois 60616 (telephone: 312/567-4193). 82-014

PLASTICS

VIBRATIONAL MOLDING

An unusual approach to molding of thermoplastic materials has been developed by the NOW Corporation and is currently being used by the firm on a production basis. Called Unifuse, the process is a vibrational microlamination molding technique carried out at temperatures below the melting point of the resin being processed. Thermoplastic material (either pellets or powder) is fed into a heated, single-surface rotating mold in a controlled environment chamber. As the plastic particles are fed into the mold, they fuse together. When the desired wall thickness is attained, the mold is taken from the chamber and cooled, and the finished part is removed from the mold. Temperature control during molding is critical since the plastic is softened but not melted.

Unifuse processing is expected to compete with the more conventional thermoplastic molding techniques, especially in fabrication of relatively large components such as bins, racks, or tanks. Parts as large as 5x5x2 feet and weighing up to 180 pounds have been manufactured. Advantages of the process include low tooling costs, the ability to produce parts without parting lines and draft angles, uniform part wall thickness, minimal degradation of physical properties of the plastic, and the absence of stress and flow patterns in finished parts. The process can be adapted to the fabrication of composites and laminates and inserts are easily incorporated into product designs. There are limitations, however, on part geometries and finishes and the type of plastics that can be molded.

For more information, contact: Mr. Robert P. Fried, NOW Corporation, Unifuse Division, Route 9G, Staatsburg, New York 12580 (telephone: 914/889-4000). 82-015

CERAMICS

SILICON CARBIDE PRODUCTION

A new process for manufacturing silicon carbide, based on a proprietary furnace design, is being investigated by Superior Graphite Company. Originally developed for production of graphite by continuous high temperature thermal processing of granular petroleum coke, the furnace is capable of operating at 2500°C. Conventional raw materials (granular coke and silica sand) are used, but the resulting silicon carbide is unique in that it consists of sub-micron size crystallites agglomerated into larger grains. Though continuous throughput of 10 tons per day is forecast for a production furnace, the company is currently producing silicon carbide on only a limited basis to refine processing parameters and establish costs. Investigations are also being undertaken to determine the suitability of the fine grained silicon carbide in such applications as sintered ceramic or refractory products and as a metallurgical additive.

In addition to the finer grained silicon carbide, the process should result in lower production costs due to automation, reduced material handling and fewer environmental control problems because of the closed system. The firm is studying possible production on a commercial basis itself, but is also considering licensing and joint venture alternatives.

For more information, contact: Dr. W. M. Goldberger or Mr. Peter R. Carney, Superior Graphite Company, 20 North Wacker Drive, Chicago, Illinois 60606 (telephone: 312/726-7939). 82-016

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SPECIAL FOCUS:
ROBOTIC TECHNOLOGY

CURRENT STATUS

Today's industrial robots are capable of performing a wide variety of manufacturing tasks, ranging from simple transport operations to more complex activities requiring dexterity, flexibility, and feedback. Robots can manipulate objects through space, performing sequences of motions consisting of hundreds of steps.

Several improvements in robotics technology are required, however, before industrial robots can achieve their full potential. Today's robots will not be able to perform complex assembly or machining operations until improvements are made in positioning accuracy and sensing capabilities. Improvements are also required in gripper dexterity, robot speed, weight lifting capability, and in the use of lightweight materials in robot arms. Finally, control and programming capabilities need to be improved to enable robots to receive complex feedback data from sensors and rapidly adjust their motions in response to this data.

RESEARCH TRENDS

The world-wide level of research and development being performed on robotics has increased dramatically during the past several years. In the U.S. alone, robotics research budgets are increasing at an annual rate of 30 to 40%. Much of this effort is directed toward achieving practical improvements in robot capabilities. Improvements in sensing, gripper design, and performance will have direct benefits to potential robot users in all manufacturing industries.

Although Japan is showing the greatest interest in robots today, many other countries are also promoting active R&D programs, including the U.S., U.K., U.S.S.R., West Germany, Yugoslavia, Italy, France, and others.

UNITED STATES

Organizations performing robotics research in the U.S. are concentrating on four basic areas of development: vision sensing, programming, control and gripper dexterity. The development of low cost vision sensing is the primary goal of many research efforts. Although several systems are available for two-dimensional vision sensing, the ability to distinguish three-dimensional objects from other overlapping objects is relatively undeveloped.

As robots become "smarter" through improved sensing capabilities, research is also being conducted on specialized grippers with greater flexibility and general-purpose grippers with better manipulative capabilities. Control systems are being improved to take advantage of these new grippers and sensors and appropriate high level programming languages are being developed. Several important developments now underway in these areas include the following:

- o <u>PUMA simulation model</u> (Rensselaer Polytechnic Institute) - This model is being developed to help PUMA robot users determine the best work arrangement for the PUMA and its surrounding equipment. The model simulates the motions of the robot and determines work cycle times required for various robot configurations.

- o <u>Three-fingered gripper</u> (Stanford University) In cooperation with the Jet Propulsion Laboratory, Stanford is developing a three-fingered gripper with nine degrees of freedom. Mounted on a PUMA robot, the gripper is activated by a series of cables attached to motors mounted on the robot arm. Each finger has an independent servo, and with three separate joints per finger, greater flexibility can be achieved in grasping parts.

- o <u>Arm Language (AL) programming system</u> (Stanford University) - Stanford has developed one of the most advanced programming languages for robots to date. The AL system was designed to provide for real time control of assembly robots using sophisticated sensors. It monitors the location of the subassembly and calculates arm positions relative to the coordinate system of the subassembly. The AL system is being tested for use with force sensors and complex assembly operations.

- o <u>Three-dimensional stereo vision</u> (Massachusetts Institute of Technology) - Currently in development, this system uses a pair of binocular TV images to produce a map of distances to each point on the object. The image is generated and processed in only one to four seconds, which should lead to many practical applications for this system.

- Three-dimensional vision system (Stanford University) - The ACRONYM vision system is being developed for inspection and picking parts from bins. This system combines geometric modeling with state-of-the-art problem solving capablities to recognize objects.

Many other organizations are conducting robotics research in the U.S. University research efforts include those of Carnegie-Mellon (vision and touch sensing), University of Florida (kinematics and dynamics), Purdue (control and programming), and Rhode Island (vision). Industrial research is being conducted by General Electric (assembly, vision, and control), General Motors (vision), IBM (programming), Westinghouse, and Texas Instruments. Other researchers include Draper Laboratories (force sensing) and SRI International (vision).

JAPAN

Research and development efforts in Japan are currently focusing on the automated factory concept. These automated factories would consist of machine tools or machining centers, robots to feed and unload parts, automatic material handling equipment, and a central computer. The Ministry of International Trade & Industry is committed to a national goal of developing an unmanned manufacturing facility during the next decade.

Universities and national laboratories are concentrating their research on improvements in positioning accuracy, sensing, pattern recognition, and speed control, while industrial research is aimed more at specific applications that require increased speed and weight reduction. Overall, Japanese research is stressing sensing capabilities, programming languages, and robot mobility. Some recent developments include:

- A Fujitsu Fanuc plant, where unmanned robots produce other robots. With only one hundred workers, the plant produces about one hundred robots per month along with NC machines.

- Mitsubishi Electric is developing an infrared vision sensor for arc welding to detect weld line irregularities.

- Fujitsu Fanuc has developed a compact robot that can recognize, sort, and assemble parts through the use of a solid-state electronic camera and built-in 16-bit microprocessor.

UNITED KINGDOM

After an initial burst of enthusiasm in the 1960's, interest declined in the U.K. until the late-1970's. Today, only a limited number of robots are in use, but research and development efforts are increasing. At the University of Nottingham, for example, a binary image vision system is being developed. Other efforts include: an inexpensive parts handling robot with sensing capabilities being developed by Patscentre International, and a teaching robot recently introduced by Didactec Engineering that shows unskilled labor how to operate automated equipment.

U.S.S.R.

The U.S.S.R. is one of the leading users of industrial robots in the world; however, their robots are less sophisticated than those used in the U.S. or Japan. Research efforts in the U.S.S.R. are supported by a strong national commitment to robotics development. Current programs are concentrating on improved programming, dynamic performance, robot control, and expanded applications. One major effort, for example, is the development of a robot cell for arc welding. A number of programs are also underway for the development of various sensing systems.

OTHER EUROPEAN DEVELOPMENTS

Robotics research is also being conducted in France, West Germany, Belgium, Italy, Czechoslovakia, and several other European countries, with emphasis on assembly applications and the development of completely automated factories. At the Institute for Production and Automation in West Germany, for example, research is being conducted on precision assembly robots using optical sensing. In France, the Commissariat a l'Energie Atomique is developing a sophisticated microprocessor controlled robot with force feedback capabilities. Another example of a promising development is a two-arm welding robot available in the U.S. from Comet Welding Systems under a licensing agreement with an Austrian firm. The robot performs welding operations more productively than single arm robots and features an improved seam tracking capability.

SPECIAL FOCUS is a regular feature covering major developments in a selected technology area.

LEADERS IN DEVELOPMENT:
BATTELLE'S COLUMBUS LABORATORIES

BATTELLE MEMORIAL INSTITUTE

Generally recognized as the first of the "not-for-profit" research institutes within the U.S., Battelle Memorial Institute began formal operations in Columbus, Ohio, in 1929. In 1980, revenues were more than $400 million and the number of staff totaled over 7,500.

Battelle Memorial Institute undertakes contract research for a wide variety of industrial and governmental sponsors. Last year Battelle had 3,500 studies in progress for over 2,000 clients in 41 countries. Although the organization has operations and facilities in many locations, most of Battelle's activities are undertaken at its four major centers in Columbus, Ohio; Frankfurt, West Germany; Geneva, Switzerland; and Richland, Washington.

Since its founding, Battelle Memorial Institute has blossomed into a widely diversified contract research organization spanning many areas of science and technology. A few of the areas of expertise include: chemical processes; computer systems; electronics; equipment design; manufacturing systems; and materials processing.

Battelle applies this expertise to its clients' needs in a variety of ways. Using contract research, individual projects are undertaken which are tailored to the sponsor's needs and resource requirements. These projects can range from basic or applied research in a particular field to product development and the application of state-of-the-art technology to specific problems. In addition to individually-sponsored projects, Battelle also conducts numerous group-sponsored programs where several clients share in the cost and results of the research.

MANUFACTURING TECHNOLOGY ACCOMPLISHMENTS

Since its founding, a majority of Battelle's research activities have involved "manufacturing technology." Examples of significant manufacturing innovations include: the first melting of titanium in electric furnaces and initial development of titaniuim alloys (1947); pioneering work in the area of electro-chemical machining (1952); development of the roll-welding process (1961); the application of acoustic monitoring techniques to determine weld quality (1968); and the development of a melt extraction process for manufacturing wire products directly from molten metal (1976). Other areas where Battelle has played a significant development role include hot isostatic processing, hydrostatic extrusion, isothermal forging and rolling, a variety of non-destructive testing techniques, and computer aided design and manufacturing (CAD/CAM).

COLUMBUS LABORATORIES

As the oldest of Battelle's four major research centers, the Columbus Laboratories (BCL) is a formidable organization, with annual revenues exceeding $110 million in 1980. A significant portion of those revenues represent manufacturing technology research and development conducted by several of BCL's ten departments, including the Engineering and Manufacturing Technology Department which has a staff of 165.

CURRENT ACTVITIES

The spectrum of on-going manufacturing technology projects at BCL include: the development of new materials and processes; analysis and resolution of specific production problems; feasibility studies; development of prototype equipment; design and fabrication of turnkey production systems; and the development and application of productivity analysis and improvement techniques.

Although most projects at BCL are individually sponsored, they also conduct many group-sponsored programs. On-going programs of this type include: cubic boron nitride wear-resistant coatings; injection molding of ceramics; injection molding of metal powders; hot isostatic processing of ceramics; and close tolerance forging of carbon, alloy and stainless steels.

In 1981, BCL established a Cooperative Center for Metal Processing (CCMP) to foster joint activities among industry, government agencies, research laboratories and universities to advance the state of the art in metal processing technology. Some of the on-going studies being conducted by the CCMP include: mathematical modeling of forming processes; CAD/CAM techniques for close tolerance forging of gears; and development of an interactive computer program for rolling process design.

CAD/CAM is playing an increasingly greater role in the on-going projects at BCL, and much of this work deals with the computerization of production equipment. Examples include special purpose welding manipulators, thermal spray equipment, and injection molding machines.

Although deeply involved in the development of CAD/CAM techniques and concepts, BCL also serves as an integrator of this technology by heading several teams of manufacturers and equipment suppliers to develop and implement larger CAD/CAM systems. For example, BCL is conducting the first demonstration project under the U.S. Air Force's Integrated Computer Aided Manufacturing (ICAM) Program. The objective of this project is to develop a CAM architecture and special computer-controlled equipment for an automated repair facility for turbine engine blades used in military aircraft. BCL's lead role in the Electronics Computer Aided Manufacturing (ECAM) Program sponsored by the U.S. Army is another example of how they serve as an unbiased integrator and catalyst in CAD/CAM.

BCL is also broadening its activities in the area of productivity modeling and analysis. During the past three years, BCL has developed and refined a computer-based productivity modeling and simulation technique which tests the effects of proposed changes on the overall productivity of an entire operation. The system uses a modeling methodology which is adapted to each organization. Included in the model are such factors as direct labor, indirect labor, financial considerations, and even areas such as the influence of regulatory constraints. Once the model has been established, it can be used to measure current productivity in terms of a baseline index, evaluate and prioritize changes which will yield the greatest productivity improvement, and provide a means for monitoring the effects of productivity enhancing actions on a long-term basis. The system is capable of modeling entire organizations with annual sales up to $250 million.

FUTURE DIRECTIONS

In the near-term, BCL will continue to offer a similar range of research services to its customers. Group-sponsored projects, for example, will be started in the following areas: CAD/CAM of forging dies for turbine engine blades; hot isostatic processing to improve casting quality; laser surface modification of materials; hot extrusion of ceramic shapes; and fracture toughness testing techniques for cast irons. Also, BCL will continue the major research and development activities started recently, such as the Cooperative Center for Metal Processing; productivity modeling and simulation; and the multi-year projects in CAD/CAM.

Several trends that will help shape BCL's long-term future direction did emerge from interviews with senior staff members. For example, interest in the development of new materials, substitute materials and new manufacturing processes which provide higher yields should increase in the future due to rapidly escalating costs and uncertain availability.

The use of computer technology in manufacturing will also continue to be emphasized, both in terms of computer-controlled production equipment and in higher levels of factory automation. For BCL, this means additional projects for the design and fabrication of automated production equipment and manufacturing systems. Also, BCL's role as an integrator of CAM technology will also become more visible in the future.

It is becoming increasingly clear that the trend during the next few years will be towards the application of existing technology rather than basic research. The techology to solve today's productivity problems already exists; the real challenge will be technology utilization. This trend is already reflected in research and development expeditures for both industry and government, where a greater portion is being used for productivity enhancement and product improvement rather than basic research and new product development. This trend, coupled with industry's increasing willingness to adopt new technology, signifies that BCL will become more of a "technology transfer" agent for its clients in the future.

BCL will continue to be a major force in manufacturing technology development, and many future contributions to productivity improvement can be expected from them.

For more information on BCL and their technology development activities, please contact:

Mr. J. E. Sorenson, Manager
Engineering and Manufacturing
Technology Department
Battelle Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201
(telephone: 614/424-5341)

LEADERS IN DEVELOPMENT is a regular feature focusing on major developers of manufacturing technology from around the world.

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TEST AND INSPECTION

AUTOMATIC DETECTION OF SURFACE DEFECTS

Rensselaer Polytechnic Institute has developed a system for the automatic detection of dents, bumps and scratches on shiny and semi-shiny surfaces. In the first stage of a two-stage inspection procedure, a grid is projected onto the surface of a part by a diffuse light source. A dent in the part will cause the lines of the grid to squeeze closer together while a bump will spread the lines apart. By means of a television camera aimed at the part, a computer measures distortions in the grid pattern, thereby identifing defects. The system has detected dents and bumps as small as 0.25 inches wide and 0.02 inches deep. Smaller defects could be detected since the system is limited only by diffraction and camera imaging ability. During the second stage of inspection, the part is illuminated from all sides with light from an oblique angle. Again, the computer examines the surface through a television camera. A smooth surface will reflect all the light away from the camera, while a scratch will reflect some light toward the lens, highlighting the scratch on a dark background. The computer processes this information to find and trace the scratch. Scratches as small as 0.001 inches wide and 0.025 inches deep have been detected.

The system can be used to inspect any relatively flat or gently curved specular or semi-specular surface including those that are painted or plated. Primary benefits include faster and more accurate inspection than possible by human inspectors.

For more information, contact: Dr. Henry Stark, Department of Electrical and Systems Engineering, Rensselaer Polytechnic Institute, Troy, New York 12181 (telephone: 518/270-6313). 82-017

AUTOMATED EDDY CURRENT INSPECTION

General Electric Company has developed a three-axis automated eddy current inspection machine for inspecting circular aircraft engine parts such as compressor and turbine disks for the U.S. Air Force. The computer controlled prototype is capable of detecting surface flaws by measuring fluctuations in induced eddy currents and recording their size and location. The system can automatically detect the size and location of surface flaws as small as .005 inches deep and .030 inches long on flat and curved surfaces, as well as such difficult to inspect areas as bolt holes and dovetail slots. GE is also slated to provide the Air Force with two pre-production machines which will have six axes of motion and improved speed and accuracy capabilities.

The GE development represents the first fully automatic inspection machine of its kind. It is much faster than current semi-automatic machines and more reliable than manual inspection techniques. This technology will enable the Air Force to accurately determine the condition of engine components and employ a "retirement for cause" replacement policy rather than discarding components after a specified number of service hours.

For more information, contact: Mr. A. Wilson, General Electric Company, Evendale, Ohio 45215 (telephone: 513/243-3189). 82-018

FLAW DETECTION IN PLASTICS AND COMPOSITES

The Massachusetts Institute of Technology has developed a system for detection of subsurface flaws in plastics, glass, polymeric composites and similar non-conducting materials. One surface of the part or material to be inspected is sprayed with an electrostatic charge while the opposing surface is held at electrical ground. An electrostatic probe is then used to measure the residual charge pattern. Flaws such as voids, cracks and impurities are detected by noting the differences they cause in the decay of the charge.

The system replaces destructive or x-ray inspection and is inexpensive, fast, simple and accurate. It is particularly effective for detecting cracks perpendicular to the surface or defects in low density materials which cannot otherwise be detected by x-ray. Basic equipment for the system can be assembled for under $5,000.

For more information, contact: Dr. Lewis Erwin, Laboratory for Manufacturing and Productivity, Massachusetts Institute of Technology, Cambridge, Massachusettes 04923 (telephone: 617/253-2249). 82-019

TEMPERATURE MEASUREMENT

An optically-based precision temperature measurement technology, called "fluoroptic thermometry," has been developed by Luxtron Corporation. Fluoroptic thermometry is based on the isolation and measurement of the relative intensities of two sharp fluorescent-emission lines from an europium-activated phosphor which is attached to the end of a light transmitting optical fiber probe. Ultraviolet radiation, transmitted through the optical fiber, is used to excite the phosphor. The resulting visible fluorescence is then sent back through the optical fiber to the measuring instrument, which isolates the desired spectral lines. The instrument compares the ratio of the two intensities with a standard calibraton curve and displays the calculated temperature or makes it available to other instruments via digital and analog output ports.

The system is capable of measuring temperatures from -30°C to 220°C with 0.1°C accuracy. Other features of the technology include small physical size and thermal mass of the probe and rapid response rate (250 milliseconds). The sensing probe, which can be located up to 50 feet from the control instrumentation, is chemically inert, non-metallic and can even be used in an autoclave. Cost for the entire system is about $7,000.

For more information, contact: Mr. Alex Cheng, Luxtron Corporation, 1060 Terra Bella Avenue, Mountain View, California 94043 (telephone: 415/962-8110). 82-020

STRESS MEASUREMENT

Southwest Research Institute has developed a system for nondestructive measurement of stresses in parts made from ferromagnetic materials. The system is based upon magnetic domain phenomena. By applying an electromagnetic current, varying magnetic fields are created which cause changes in the magnetic domains within the part being inspected. As the domains abruptly change their configuration, voltage pulses are generated which can be analyzed to reveal stress conditions. The system is capable of measuring stresses to a depth of .02 inches below the surface and can detect sharp stress gradients within a surface area of .05 square inches. Use of the technique does not require the removal of rust or paint, and the small size of the test probe permits stress measurements to be made in areas typically considered inaccessible. The system was originally developed for measuring residual stresses in critical steel parts used in helicopters. Many other potential applications exist, including inspection of railroad car wheels, ball bearing races, turbine blades and shot peened parts. Cost to implement the system is about $30,000.

For more information, contact: Mr. John Barton, Southwest Research Institute, 6220 Culebra Road, P.O. Drawer 28510, San Antonio, Texas 78284 (telephone: 512/684-5111). 82-021

HARDNESS TESTER

A new computerized semiautomatic hardness tester from Engineering and Scientific Equipment, Ltd. (Middlesex, England) can test the hardness of steel in the Rockwell C scale in less than 15 minutes. Conforming to International Standards Organization (ISO) recommendation R642, the tester includes a computer, printer and chart recorder. Robot devices are also available for complete automation. Each machine is programmed for various tests according to the user's specification, but modifications or new specifications can be keyed in by the operator. The system features a precision test point positioning system with a resolution of 1 micrometer, which eliminates the need to precisely determine the test-point locations.

Tests which might have taken skilled operators a month to perform can be carried out in a single day. The equipment provides an immediate printout of data and analysis of the results. The recorder also draws colored graphs to indicate deviations from specifed tolerances.

For more information, contact: M. J. Shrago, Engineering and Scientfic Equipment Ltd., 22-26 Mount Pleasant, Alperton, Wembley, Mddlesex HAO 1TU England (telephone: 01-903-4721). 82-022

COMPUTER-AIDED MANUFACTURING

WORK CELL SIMULATION

An animated work cell simulator has been developed by McDonnell Douglas Aircraft Company to model the physical motion within a manufacturing cell. The prototype system, called ANIMATE, is a graphics package that can simulate the smooth animated motions of a single robot or an entire work cell containing several robots, machine tools and other material handling equipment. The work cell simulation is driven by output from MCL (Machine Control Language), an advanced machining language developed by McDonnell Douglas Aircraft Company for the U.S. Air Force's Integrated Computer Aided Manufacturing (ICAM) program. ANIMATE preforms geometric modeling on MCL program data to produce the cartoon-like graphical simulation of the work cell.

ANIMATE permits the visual checkout of the total manufacturing environment before a commitment to actual hardware is made. The system allows for the quick and economical review of entire production lines as well as individual processes so as to avoid costly mistakes in the future. McDonnell Douglas Automation Company is currently considering marketing the ANIMATE system to other companies. Similar graphics simulation work is currently being conducted by Hitachi (Japan) and Renault (France).

For more information, contact Mr. Jim Beecher, McDonnell Douglas Aircraft Company, P.O. Box 516, St. Louis, Missouri 63166 (telephone: 314/232-4121). 82-023

COMPUTER IMAGING

Researchers at NASA's Dryden Flight Research Center have developed an efficient and effective new program for computer imaging of three-dimensional shapes, surfaces and groups of objects, regardless of complexity. The solution permits the computer to depict an object from a specific viewpoint just as the human eye would see it and not show all the objects' hidden surfaces, angles and curves.

The major significance of the NASA development is its speed and ability to handle complex objects or groups of objects. Recent computer testing at Lawerance Livermore Laboratory has verified the computer program's superiority over existing imaging systems with respect to speed, accuracy and generality.

For more information, contact: Mr. David Hedgley, NASA Dryden Research Center, P.O. Box 273, Edwards, California 93523 (telephone: 805/258-3311 ext 225) 82-024

MACHINING DATA BASE

Both Metcut Research Associates and Ford Motor Company have recently developed computerized data bases for machining information. Typical data base information includes machine tool types and capabilities, machining parameters for various workpiece materials, and tool life. Attempts have also been made to capture the logic used by engineers and planners to permit the development of more sophisticated data bases.

The successful development of such data bases is necessary to achieve higher levels of computer-aided manufacturing, particularly in the areas of process planning, cost estimating, capacity planning and production control. In the near-term, rapid access to machining data would be a major benefit to process planners, tool analysts, and process engineers. As labor costs increase and the availability of skilled personnel continues to decline, machinability data bases will also be needed to reduce costs and retain hard-earned knowledge.

For more information, contact Mr. Jeff Lindberg, Metcut Research Associates, 3980 Rosslyn Drive, Cincinnati, Ohio 45209 (telephone: 513/271-5100 ext. 261) or Dr. Sanaa R. Taraman, Manufacturing Development Center, Ford Motor Company, Detroit, Michigan 48239 (telephone: 313/592-2640). 82-025

ELECTRONICS PRODUCTION

ELECTRONICS COMPUTER AIDED MANUFACTURING

The U.S. Army has recently initiated a major program in Electronics Computer Aided Manufacturing (ECAM). The first program phase, funded for almost $2 million, will produce a "Master Plan" to guide future government investments in technology developments for computer-aided design, manufacture and test of electronic equipment. The plan is being developed by a broad coalition of electronics manufacturers and other firms led by Battelle Columbus Laboratories. It will include descriptions of specific technology developments that should be undertaken, estimated costs, relative priorities, time phasing and anticipated benefits. The approach being used to prepare the plan is to develop a model of a fully automated electronics factory and to compare it to current state-of-the-art techniques for design, manufacture and test; the differences between the idealized model and existing methods will be used to identify future development needs.

The initial ECAM work is expected to be only the beginning of an ambitious effort to produce major improvements in small batch production of electronics equipment through the application of computers and advanced automation. Total government expenditures for the program are expected to run as high as $200 million. However, tangible results from future technology development and demonstration programs are not expected for some five to seven years.

For more information, contact: Dr. Al Robinson, Battelle Columbus Laboratories, 505 King Avenue, Columbus, Ohio 43201 (telephone: 614/424-6424) or Mr. Gordon Little, U.S. Army Missile Command, Attn: DRSMI-RST, Redstone Arsenal, Alabama 35809 (telephone: 205/876-3604). 82-026

ELECTRONICS AUTOMATION

Computer Aided Manufacturing-International, Inc. has announced the formation of a group-sponsored Electronics Automation Program for the development and application of computer-aided design and manufacturing (CAD/CAM) techniques within the electronics industry. Possible projects within the program include creation of an electronic components data bank; development of an integrated framework for electronic product design, manufacture and test; and design of a data exchange interface for electronics CAD/CAM that would allow various systems to communicate with one another.

For more information, contact: John Bell, Computer Aided Manufacturing-International, Inc., Suite 1107, 611 Ryan Plaza Drive, Arlington, Texas 76011 (telephone: 817/265-5328). 82-027

AUTOMATED WAVE SOLDERING

A computer-controlled wave soldering machine has been developed by Westinghouse for the U.S. Army. As part of the development, Westinghouse investigated a number of parameters affecting the wave soldering process and concluded that conveyor speed, rather than soldering temperature, should be used as the primary control variable. The new machine also incorporates several other features, including: improved fixturing for better board protection and reduced sensitivity to wave flow characteristics; fresh rather than recirculated fluxing that eliminates the need for preheating; and intermittent operation of the solder pump to reduce dross formation.

Preliminary trials indicate yield increases of 1% over manually operated wave soldering machines run by experienced operators and much greater yield improvements for new operators. Although capable of being implemented in almost any plant, the relatively high cost of the system makes it more appropriate for large production facilities which experience high operator turnover. Westinghouse is currently refining the design and implementing the system in one of its facilities, with implementation also slated for at least one other location. Additional development efforts planned by Westinghouse in the printed wiring board area include automated loading and unloading equipment, robotics for automated assembly and laser soldering.

For more information, contact: Mr. W. A. Ernst, Westinghouse Defense and Electronics System Center, Box 1693, Baltimore, Maryland, 21203 (telephone 301/765-2256), or Mr. Lloyd Woodham, U.S. Army Missile Command, DRSMI-RSI, Redstone Arsenal, Alabama 35898 (telephone: 205/876-2147).

Another approach to automated wave soldering is being independently developed by Electrovert Inc. The Canadian-based firm is currently re-designing their manually operated wave soldering machine to eliminate operator control of process parameters. The automated machine will feature microprocessor monitoring and, unlike the Westinghouse approach, will control more than one parameter.

The newly designed machine is expected to increase soldering throughput by as much as 50%, especially for high quality boards, and will include maintainability and cleaning features to decrease machine downtime. Electrovert is hopeful that the new machine, expected to be available late in 1982, will be priced at a level which is attractive to even small manufacturers.

For more information, contact: Mr. Michael Mittag, Electrovert, Inc., 399 Executive Blvd., Elmsford, New York 10523 (telephone: 914/592-7322). 82-028

PRINTED WIRING BOARD PRODUCTION MODULES

To reduce printed wiring board (PWB) production losses due to contamination, DuPont is developing a series of three totally enclosed PWB manufacturing modules. The first module provides for board feeding, cleaning and resist application. The second performs automatic registration, photo imaging, etching, washing and dryng. The third module recycles waste products. The equipment will handle both single- and double-sided boards with a maximum throughput of 12 feet per minute. Photomask changes take about two minutes. The first module has been demonstrated at a recent trade show and will be available from Dupont, along with the second module, during 1982. The third module is scheduled for market entry in 1983.

The benefits of this equipment include up to a six-fold reduction in production labor, a reduction of photoresist waste from 10 to 15% to about 1% and improvement in board yields.

For more information, contact: Ms. Priscella Tuminello, Attn: MCD (MTH), Room N-2524-2, DuPont, Wilmington, Deleware 19198 (telephone: 302/773-3218). 82-029

GLASS PHOTOMASK

Precision Art Coordinates, a subsidiary of PPG Industries, has developed an "Image Plane Plate" photomask suitable for high density, fine line printed circuit boards, as well as chemically machined parts and liquid crystal displays. Unlike conventional photomasks having an emulsion coating which can be scratched during cleaning and handling, the new mask has the image imbedded in the glass plate, from the surface to a depth of 3 microns. Although the company will not disclose details of how the image is placed in the glass, it is known that there are no coatings of any type applied to the glass surface. Line resolution for the new photomask is 1 mil or less.

Advantages of the new mask include: exceptional durability and dimensional stability, opaqueness to ultraviolet light, transparency for accurate alignment, and cleanability. Initial production of the masks is scheduled for early 1982.

For more information, contact: Ms. Jean Wright, PPG Industries, One Gateway Center, Pittsburg, Pennsylvania 15222 (telephone: 412/434-3019). 82-030

PC BOARD INSPECTION

Chrysler Corporation has developed an automated printed circuit board inspection system for the U.S. Army. Using two helium neon gas lasers, photo-multipliers and a microcomputer, the system scans the underside of the boards to detect missing components, improper component lead lengths and bends and solder bridging. Inspection speed is typically 15 to 20 milliseconds per lead, with no limit on the size of board that can be inspected. Accuracy is reportedly near 100%. Defective boards are assigned a serial number by the system and the location and type of defect is automatically documented to simplify board repair. The system is intended for in-line inspection and performs real-time trend analysis on defects. When pre-programmed defect limits are exceeded, the system can either sound an alarm or shut down the production line. Future development work could expand the system's capabilities to include inspection of other defects, such as excess or lack of solder.

Chrysler already has one prototype in use and was able to eliminate two inspectors from the line. Cost of the system is about $100,000, and payback period is estimated at one year. Chrysler intends to manufacture and market the system itself.

For more information, contact: Phil Geise, Chrysler Corporation, Huntsville, Alabama 35800 (telephone: 205/895-1790) or Robert Brown, U.S. Army Missile Command, Attn: DRSMI-RST, Redstone Arsenal, Alabama 35898 (telephone: 205/876-5942). 82-031

BOOKS AND REPORTS

LASER PROCESSING

Technical Insights has prepared a 201-page report on laser processing of chemicals and materials. Numerous emerging technologies are covered in the report, including: surface treatments, particularly in semiconductors; generation of radicals as reaction precursors; removal of trace impurities in semiconductors; and isotope separation. Price of the report of $465.

For more information, contact: Kenneth Kovaly, Technical Insights, Inc., P.O. Box 1304, Fort Lee, New Jersey 07024 (telephone: 201/944-6204). 82-032

INDUSTRIAL ROBOTS

Tech Tran's 167-page special report, Industrial Robots: A Summary and Forecast for Manufacturing Managers, provides an up-to-date and comprehensive overview of the subject. Topics covered include basic technology of industrial robots, capabilities and applications, economics of use, equipment selection, and anticipated future developments. Price is $50 in the U.S., Canada and Mexico; $65 elsewhere.

For more information, contact: Tech Tran Corporation, 134 N. Washington Street, Naperville, Illinois 60540 (telephone: 312/369-9232). 82-033

OTHER INTERNATIONAL NOTES

FUSIBLE-METAL CORES

A joint effort by Ford Motor Company, BTR Permali Ltd. and Fiberglass Ltd. has resulted in the use of hollow fusible-metal cores for molding glass-reinforced polyester automotive engine components. The hollow fusible-metal cores are formed from a tin/bismuth alloy. After molding, the cores are removed from the part by immersion in a heated oil bath. The alloy is then re-cycled into new cores. 82-034

COLD PHOSPHATING

Redic Industries Pty Ltd. (Australia) has reportedly developed an effluent-free cold phosphating process which degreases, phosphatizes and deposits a polymer film in a single step. The process requires only a single tank, occurs at ambient temperature, and is extremely rapid (about one minute). Cast iron, steel, aluminum, and galvanized steel can be treated. Additionally, all conventional coatings (both powder and liquid form) can be applied to the treated metal surfaces. 82-035

SAND BINDER

Researchers at Warsaw Polytechnic (Poland) have developed a new water-soluble binder for sand casting cores. The binder contains sodium carbonate and sodium hydroxide. Core hardening is accomplished by blowing carbon dioxide through the core box. Immersion of the casting in cold water causes the core to crumble quickly. The core sand then flows easily from the casting and can be completed regenerated. It is possible to fabricate both core and mold using the binder and subsequently recover the finished casting by immersion in water. 82-036

FLEXIBLE MANUFACTURING SYSTEM

Herbert Warnke Kompagnie (East Germany) a manufacturer of large presses and metal forming machines, has implemented a flexible manufacturing system with large part handling capabilities. Referred to as the PC-3, the system is able to machine 24 ton parts up to 8 meters in length. Fully operational, the system contains five turret lathes, an automated material handling system, and an automated warehouse facility. Warnke engineers report that the automated system has eliminated the need for seven machine tools, reduced labor by 50,000 man-hours per year and requires 500 square meters less floor space than previously needed. 82-037

ELECTRO-MAGNETIC CONTROLLED WELDING

Kawasaki Steel (Japan) recently reported the use of an electroslag welding process for overlaying stainless steel linings on steel base metal. Current flowing between a consumable electrode and the base metal melts a high conductivity flux which in turn melts the surface of the base metal and the electrode, bonding a layer of overlay metal on the base. The electroslag technique reduces weld dilution ratio to about 10% and permits use of electrodes as wide as 6 inches. A key feature of the process is the use of an external magnetic field to control flow of slag and metal in the fusion zone. Solenoids near the welding head induce a magnetic field perpendicular to the base metal which causes slag and molten metal to flow from the center of the pool to the edges of the weld zone. This control of the weld pool results in improved flatness of the overlay, particularly in overlaps between two passes, and reduces undercutting of the base metal at the edges of the weld bead. Other benefits include superior weld quality and higher deposition rates. 82-038

SHELL MOLDING

Asaki Yukizai Kogyo Co., Ltd. (Japan) has announced the development of a new resin for use in shell molding of aluminum castings. The denatured phenol resin used to coat the sand provides better collapsibility of the mold after casting. No post-casting baking is required to collapse the mold, which is typically the case with conventional phenol coated sand systems. 82-039

MTH 125 - John C.

WATERJET CABLE STRIPPING

Flow Systems has developed a unique method of using water to strip cable insulation. This system uses a 0.004 to 0.008 inch diameter cutting nozzle which can discharge a waterjet at pressures up to 55,000 psi. Cable ranging from 1/4 inch to over 2 inches can be efficiently stripped with no damage to the metallic conductor. This process is capable of either continuous stripping operations or stripping only the end of cables. Stripping speeds of 50 to 120 fp, have been achieved on 1/2 inch od cable with 1/8 inch thickness of insulation. Stripping speeds vary with waterjet nozzle pressures.

This system represents a significant improvement over other wire strippers. Now it is possible to recycle large diameter wire. In the past, it was extremely difficult to remove insulation without damaging the conductor on large diameter wire. This process has made it feasible to remove the insulation on a continuous basis by using feeder and take-up spools. The uniqueness of this process is that no damaging forces are applied to the conductor during the stripping operation. Although the machine is expensive, ranging in cost from $70,000 to $100,000, it can be justified through significant increases in productivity. Productivity was tripled on 1/2 inch od wire with 1/8 inch thick insulation and increased 100 percent on 2 inch od wire with 1/2 inch conductor because of the difficulty in stripping this size wire.

For more information, contact: Mr. Rod Draughon, Senior Product Manager, Flow Systems, Inc., 21414 68th Avenue South, Kent, Washington 98031 (telephone: 206/938-3569).

MTH 129 - John C.

IR DETECTORS MONITOR PCB DRILLING

IR DETECTORS MONITOR DRILL PERFORMANCE

Under the Army's Manufacturing Methods and Technology Program Hughes has successfully demonstrated the use of IR detectors to monitor the temperature increase during the drilling operation of MLB panels. An IR radiation scope and a fiberoptic thermal monitor were each used to measure drill temperature as it exits from the hole. Each system provides an inexpensive method of monitoring drill wear and can be used to automaticlaly trigger shutdown of a drilling operation. These systems cost approximately $8,000 and are easy to implement and operate.

To date, this process has only been implemented in a R&D facility. Important issues must be addressed before commercial viability is assured. First, the IR thermal monitors need to be modified to improve the temperature response of the sensor and an optical filter is required to reject extraneous IR radiation interference. Secondly detailed data needs to be developed to correlate drill size, temperature, PCB material and drill wear. This system could significantly reduce the problem of epoxy smearing over the inner layers of copper on MLBs.

For more information, contact: Jack Quintana, Hughes Aircraft Co., Bldg. 604/C255, 1901 Malvern Street, Fullerton, California 92634 (telephone: 714/732-1504).

APPENDIX L

MANUFACTURING TECHNOLOGY HORIZONS PROMOTIONAL LITERATURE

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Editor: Marianne J. Archibald **Phone: (312) 369-9232**

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134 NORTH WASHINGTON STREET
NAPERVILLE, ILLINOIS 60540
(312) 369-9232

NEWS RELEASE

FOR RELEASE: IMMEDIATE

CONTACT: M. ARCHIBALD
MANAGING EDITOR
PHONE: (312) 369-9232

NEW PUBLICATION ON MANUFACTURING TECHNOLOGY DEVELOPMENTS

CHICAGO (August 31)--Tech Tran Corporation announced that in January 1982, it will begin publication of MANUFACTURING TECHNOLOGY HORIZONS, a bi-monthly digest on new production technology. Written for manufacturing and engineering executives, it will report on current developments which are likely to have a major impact on future manufacturing operations and productivity.

International in scope, MANUFACTURING TECHNOLOGY HORIZONS will advise readers on current developments taking place in government laboratories, research institutes, equipment manufacturers, trade and professional organizations, private manufacturers and universities.

A special report, "Industrial Robots-A Summary and Forecast for Manufacturing Managers" will be provided free until December 15, 1981, to charter pre-paid subscribers. This limited edition 100-page study, prepared by Tech Tran, provides the latest information on industrial robots including their applications, economic considerations, future prospects and practical guidelines for selection and implementation.

"Today's rapidly changing manufacturing environment compels management to stay abreast of current technology," stated Tech Tran's president John Meyer. "Many major technological developments are not widely publicized, and our goal is to report all major advances in manufacturing technology while they are taking place."

For additional information on MANUFACTURING TECHNOLOGY HORIZONS, contact: M. Archibald, Managing Editor, Tech Tran Corporation, 134 N. Washington Street, Naperville, Illinois 60540 (312-369-9246)

END

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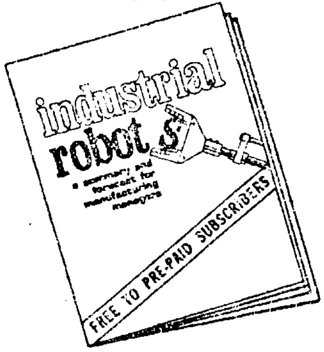

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APPENDIX M

INTERN'S SUPERVISOR'S

FINAL LETTER REPORT

TECH TRAN CORPORATION
134 NORTH WASHINGTON STREET, NAPERVILLE, ILLINOIS 60540 (312) 369-9232

September 7, 1982

Dr. Robert E. Young
College of Engineering
Department of Industrial Engineering
Texas A&M University
College Station, Texas 77843

Subject: John A. Campbell's Doctor of Engineering Internship

Dear Dr. Young:

As you know, John conducted his internship at Tech Tran Corporation from September 8, 1981 to April 30, 1982. During that period, he served as an Associate Engineer with the firm and worked on several assignments under my direct supervision. In my opinion, John has successfully fulfilled the objectives of his internship.

During his employment at Tech Tran, John worked on three major assignments. First, and probably most significant, he participated in the preparation of a major report on the current status and future trends in industrial robots. Working with other senior Tech Tran personnel, John participated in the entire spectrum of activities required to produce the report, from initial project planning through actual preparation of final text. The report has been extremely well received by professionals in the field, and John's contributions to this success were significant.

Secondly, John worked on a major project Tech Tran undertook for the U.S. Army Missile Command. His primary role in the project was the investigation and documentation of a number of manufacturing technology developments funded by the sponsor, particularly in the area of electronics production processes and equipment.

Lastly, John also served as an Associate Editor for Tech Tran's Manufacturing Technology Horizons, a bi-monthly digest on new production technology. As an Associate Editor, he investigated innovative developments in production processes and equipment and drafted summaries for publication in the digest.

Collectively, I believe these assignments have given John the opportunity to experience some of the more pragmatic aspects of being a consulting engineer. In addition to being exposed to a variety of technologies, he was also able to involve himself in a number of real-world issues and methodologies relating to project planning, information collection and analysis, communication skills, client interaction, project management and performance under constrained resources. The contrast provided by the environment of a small firm, as compared to a large, highly structured organization, should have also provided John with insights which will be valuable during his career development.

Again, I believe John has successfully fulfilled the requirements of the internship program as demonstrated by his performance at Tech Tran. I look forward to receiving a copy of his internship report and, if possible, serving on his graduate committee during his oral examination.

Sincerely,

John D. Meyer
President

JDM:cmk

cc: LTC Kitch
J. Campbell

Vita

John Arthur Campbell

1103 Allen Forest

Bryan, Texas 77801

Birthplace: Millcreek, West Virginia

Birthdate: June 23, 1947

Parents: Jesse A. and Juanita M. Campbell

Family: Married with one son

Education:

B.S., Industrial Engineering
West Virginia University, 1974

M.S., Industrial Engineering
Texas A&M University, 1980

Experience:

August 1979 - Present
Graduate Research Assistant
Texas A&M University

August 1982 - December 1982
Lecturer (Industrial Engineering)
Texas A&M University

September 1981 - April 1982
Engineer (Doctor of Engineering)
Tech Tran Corporation
Naperville, Illinois

March 1975 - July 1979
Manufacturing Engineering Officer
Space and Missile Systems Organization
Los Angeles AFS, California

May 1970 - February 1975
Medical Service Specialist
Andrews AFB, Maryland

The typist for this report was Patricia A. Campbell