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A SIMPLIFIED CONTROL MULTIPURPOSE ROBOT (SCMPR)

BY
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**A thesis submitted in partial fulfillment
of the requirements for the degree
Master of Science
Major in Industrial Management
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1989**

A SIMPLIFIED CONTROL MULTIPURPOSE ROBOT (SCMPR)

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Dr. Duane E. Sander Date
Thesis Adviser

Terry Forest Date
Head, General
Engineering Department

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ACKNOWLEDGEMENTS

I would like to thank my advisor, Dr. Duane Sander, for his advice and encouragement. I especially thank my wife, Chong Hui, for believing in me and my son, Alex, for the smiles during the rough times.

TDN

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A SIMPLIFIED CONTROL MULTIPURPOSE ROBOT (SCMPR)

THE THREE LAWS OF ROBOTICS

> 1-A robot may not injure a human being, or, through inaction, allow a human being to come to harm.
> 2-A robot must obey the orders given it by human beings except where such orders would conflict with the First Law.
> 3-A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.
>
> Isaac Asimov(1)

I. INTRODUCTION

A. What Is a Robot?

1. Introduction

Robots are found throughout our society working in industry, providing security, performing military service, exploring oceans and space, and functioning in other areas. Images of robots are found in popular movies and books. Experimenters are often in the news demonstrating new capabilities robots have obtained in reasoning, vision, tactile sensing, and locomotion. Robot technology is rapidly developing to the point where the dream of a robot imitating a person will soon become a reality. Yet, there is still no practical form of a domestic robot commercially available in an affordable price range for the average citizen. Therefore, the purpose of this investigation is to examine what types of robots are currently available and to develop a practical general purpose domestic robot in a price range affordable to the average consumer.

2. Source of the Word "Robot"

Defining a robot is a complicated task. There are numerous definitions each tailored to a particular view of a robot. Some of the more common definitions of robots and robotics will be presented with a brief discussion of their implications. Then, a new definition of a robot will be presented that is applicable to all the various types now in use.

The word **robot** was coined by the Czech playwright Karel Capek for his 1921 play, R.U.R. (Rossum's Universal Robots). It is derived from the Czechoslovakian words **robota,** meaning obligatory work or servitude,(2) and **robotnik,** meaning slave.(3) It was used in the play to describe the man-made humanoid slaves who later rebelled against their human masters. Isaac Asimov, the well known science and science-fiction writer, later created the word **robotics** for a novel about the manufacture of androids. It was Asimov's writings that inspired Joseph Engelberger, known as "The Father of Robotics."(4)

3. Definition of "Robot"

When most people think of a robot or robotics, they tend to think of the dictionary definitions. These definitions, according to The American Heritage Dictionary, include: "1. A mechanical device that resembles a human being and is capable of performing human tasks or behaving in a human manner. 2. A person who works mechanically without original thought. 3. A machine or device that works automatically or by remote control."(5) Robotics is simply defined as: "The study and application of the technology of robots."(6) A similar and somewhat lengthier definition for robot may be found in Webster's.(7)

Definitions of robotics differ mainly in that they use different implied definitions of robot, such as the following example: robotics is "The design, use, and operation of machines, which are computer controlled by algorithm, to do human-desired tasks."(8) This implies that robots are machines "which are computer controlled by algorithm." Since the key to the definition of robotics is the definition of robot, let us accept the dictionary definition of robotics and concentrate on defining a robot.

The first definition (a mechanical device that resembles a human being and is capable of performing human tasks or behaving in a human manner) comes from the popular notion of the robot as developed in science fiction books and movies. It is accurate for a humanoid robot, one that resembles a human being, but ignores all the various shapes and types used by industry and hobbyists. This is the type of robot that is often confused with an android, an artificial person made from biological materials. These robots (and androids) exist only in movies and in people's imaginations.

The second definition (a person who works mechanically without original thought) is for comparison. Basically it says: If a man acts like a machine, call him a machine. While this use of the word robot has its place, it does not define what types of machines may be called robots. However, it does imply that machines that are called robots are incapable of original thought.

The third definition given (a machine or device that works automatically or by remote control) is so general that it could include such devices as a VCR or a dishwasher. It is also open to wider interpretation because of the term "remote control." **Remote control** may be defined as "the ability to influence the actions or reactions of a circuit or device from a point which is removed, directly or indirectly, from the unit, proper."(9) Remote control could therefore be as ethereal as a radio link or as direct as a simple lever and fulcrum. This leaves the door open to labeling any number of machines as a robot that are obviously not intended to be.

In an attempt to create a standard definition for a robot, the Robot Institute of America (RIA) consulted with Joseph Engelberger and put forth the following: "A robot is a reprogrammable multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks."(10) This definition is well suited to an industrial robot, which is usually a mechanical arm controlled by some type of computer. A shortfall of this definition, however, is that it does not include robots that are operated by remote control instead of by computers or other devices. These robots include certain types designed to do work such as disarming bombs and undersea salvage, among others.

A more general definition may be obtained from the Robotics Sourcebook and Dictionary. It defines a robot as "a mechanical device that can be programmed to perform some task of manipulation or locomotion under automatic control."(11) This definition allows for devices that do not manipulate, but simply move themselves. However, it still excludes remote control devices without a programmable control system.

The Japanese, the leading users of robots, have attempted to solve the definition problem by establishing definitions for different classes of robots as follows:

MANUAL MANIPULATOR-a manipulator worked by a human operator.

FIXED SEQUENCE ROBOT-a manipulator that performs successive steps of a given operation repetitively according to a predetermined sequence, condition, and position. Its set information cannot be easily changed.

VARIABLE SEQUENCE ROBOT-a manipulator similar to the fixed sequence robot, but whose set information can be changed easily.

PLAYBACK ROBOT-a manipulator that can reproduce operations originally executed under human control. A human operator initially operates the robot to feed in the instructions-relating to sequence of

> movement, conditions, and positions-which are then stored in the memory.
>
> NC (NUMERICALLY CONTROLLED) ROBOT-a manipulator that can perform a given task according to the sequence, conditions, and positions commanded via numerical data, using punched tapes, cards, or digital switches.
>
> INTELLIGENT ROBOT-a robot that can itself detect changes in the work environment, using sensory perception (visual and/or tactile), and then, using its decision-making capability, can proceed with the appropriate operations.(12)

These definitions are much more comprehensive than any presented thus far. They include nearly every machine that is presently considered a robot except those that merely act as transporters and those known as "showbots," neither of which are manipulators. These definitions, however, still do not define a robot, but instead define types of robots. Using these definitions to describe a robot is akin to using definitions of amphibians, reptiles and mammals to describe what an animal is.

So, what is a robot? With cybernetics providing mechanical replacements for human parts, it has been argued that even man is just a biological robot.(13) If we accept only machines as robots, the widely varying types must have a common link that makes them robots. The definition used in this thesis will be: **A robot is a manipulator and/or transporter that is controlled by computer and/or indirect remote control and is capable of performing various tasks.** (A task may be defined as "one completed action, or one complete cycle."(14)) This definition eliminates the major objections of the previous definitions. It eliminates devices that are only remote controlled, such as toy cars, and devices that cannot move or cause movement, such as VCR's. The requirement for the performance of various tasks eliminates simple machines that repeat the same actions continuously. It allows for robots that perform work either by manipulating or by transporting materials and for either computer or indirect remote control.

One major category of robot does not fit this definition: the "showbot." The showbot is the type of robot often seen doing promotionals or entertaining at gatherings. It presents the outward appearance of a robot (usually humanoid to some degree), but cannot perform any useful tasks. It is usually operated remotely and is used to simulate an intelligent robot through the use of recorded or radio transmitted voice. In some cases, there is no voice and the "robot" does nothing but move. The showbot does not fit the definition of a robot presented because it is not a true robot, but is instead an imitator.

Another type of device is being constructed today that is being called a robot, but does not perform work. Since the source of the word robot comes from work and slavery, it would not be fitting to extend the definition of robot to include such a machine. These devices imitate living creatures in action and appearance, but perform no useful tasks. Such a device would be more aptly named a **simulacrum**. Examples of these devices will be presented in a later section.

4. Summary

A robot is difficult to define due to the many types now in existance. As new types are developed, definitions will continue to change. The information presented thus far hopefully has given a clearer view as to what a robot is and how the name has grown and changed in meaning.

B. Why Robots?

1. Introduction

Now that a robot has been defined, the next appropriate question is: Why robots? Why should they exist and if they should, what should they do and how should they be used? To answer these questions, the current uses for which robots are being developed will be examined.

2. Making Life Easier

Robots can be used to make life easier. This is a common theme in science fiction stories where robot butlers, maids, and housekeepers run about doing our menial labor. Their purpose would be similar to many of our modern conveniences, such as dishwashers and washing machines, in that they would perform many of our more time-consuming and burdensome tasks. A common dream throughout the history of robotics has been a world where robots perform all the work and act as our servants while we (mankind) are freed to follow our dreams. However, there are dangers to this dream that are often overlooked. Such a life of ease can lead to a loss of ambition and stifled development such as that caused by the use of slave labor in ancient Rome. Jack Williamson, author of The Humanoid Touch,(15) brings to life worlds of horror where robot servitude has been developed to such an extreme that humans are not allowed to do anything for themselves. In his stories of an ideal gone wrong, humans actually flee their robot servants in a vain attempt to build their own lives.

3. Making Life Safer

Robots can be used to make life safer. Robots are capable of performing tasks that are dangerous to life and limb. They can be built to withstand potential threats and they can be replaced in the event of failure. Robots have been used for such dangerous tasks as bomb disposal and deep sea salvage. Future robots may act as policemen and soldiers. The question to be answered when using robots to make life safer is: How safe do people want to be? A safe life can be a very boring life.

4. Making Life More Pleasant

Robots make life more pleasant by entertaining people. Small robots are sold as toys and provide hours of pleasure while some robots and imitations of robots appear on TV and in movies. Robots can be used as pets and playmates. Some people receive pleasure from robots simply by building or programming them. Others derive pleasure from ownership and the perceived enhancement it gives to their status. Future robots will be people's companions and may even be friends.

5. Extending Our Capabilities

Robots extend our human capabilities. They act as surrogates in dangerous environments and perform tasks of which humans are physically incapable. Robots can be built to survive radiation, heat, pressure, toxic gasses, etc.. They can be built to perform feats of strength and endurance beyond human abilities while maintaining incredible levels of precision. Robots have explored the oceans of the earth and the surface of the moon and Mars. Plans for the future include a robot crew to search for planets in another solar system aboard the unmanned nuclear starship Daedalus.(16)

6. Economic Gain

Probably the most common and controversial reason for building robots is for economic gain. Robots can be used to work in factories and perform many of the jobs humans do. They can be worked without breaks 24 hours a day. They don't join unions, ask for raises, or present complaints. They produce higher quality work and, with proper maintenance, they can be worked for years. Robots have often been presented as the answer to lagging productivity in American factories, even though studies have shown that the number of robots has little to do with how successful a company is.(17) In order to have a positive impact, the robots need to be tied into a larger network of computers and numerically controlled machines, the type of work performed must be suitable for a robot, and the cost of wages paid must be high enough to make the robot more economical. The robot requires a high initial investment in capital, which may not be available, and must be fully utilized to recover the investment. Even though a robot can't join a union (at present), it can't be laid off, either.

A study of General Motors, one of America's leading users of robots, shows why robots are being used. From 1970 to 1980, wages at GM rose 240% while the cost of purchasing a robot rose only 40%. In 1980, the cost to the automaker of buying and operating a robot for two shifts for eight years was $6 per hour while the total compensation for an autoworker was $20 per hour.(18)

Robots are one of many new labor displacing technologies that are being used to wipe out unskilled jobs. The controversy with robots in industry stems from the fact that robots actually replace workers. At the beginning of the 1980's, the average robot in a GM plant displaced 1.7 workers and in a three shift manufacturing plant displaced 2.7 workers. These numbers are the net after taking into account the additional workers required to install and maintain the machines.(19) The result is that manufacturing industries are becoming more productive, with output growing while employment drops.

Does this mean there are fewer jobs and more unemployed? No! As manufacturing jobs in the U.S. disappear, jobs in service related areas are booming. A five year study by the Bureau of Labor Statistics, from January 1979 to January 1984, of 5.1 million displaced workers showed that two thirds had new jobs within six months and that 45% earned as much or more than they had in their old jobs.(20)

7. Summary

Robots have great potential to enhance our lives. They have proven useful in numerous ways in the past and their future uses are limited only by our imaginations and our technology. Robots were created with the idea of making our lives better and they will always be a boon as long as we remember this when designing future robots. Robots should continue to be developed and given new abilities to serve mankind, but care must be taken to ensure that we do not sacrifice ourselves to our technology in the name of profit.

C. What Is Available?

1. Introduction

Robots have been shown to have many potential uses, but what is available to us now? This section will answer that question and will especially look at what is available to the average consumers.

Today's technology has much to offer to robot designers. New end effectors, sensors, and microprocessors give robots the ability to perform tasks once considered possible only by humans. Most Americans today are aware of the advances in microprocessors, but a brief look at the end effectors and sensors available is in order before examining the robots that use them.

The end effector of a robot is to the robot what the hand is to humans. The end effector can be either a gripper or a tool. Grippers are used to handle parts, materials, or tools. They come in numerous shapes, sizes, and types and are usually mounted on robot arms either singly or in pairs. Types of grippers used include mechanical, vacuum cup, magnetic, adhesive, and others.

Mechanical grippers are the closest imitation of the human hand. The typical mechanical gripper has two "fingers," but may have three or more. Various types of lever combinations and actuation methods are used to allow these grippers to apply a concentrated force to a single area. These grippers are used to perform various tasks in a manner similar to a hand. The mechanical gripper is the most versatile type of gripper available.

Vacuum cup grippers use suction in order to grab smooth, flat surfaces such as plate glass or sheet metal. They use either a vacuum pump or a venturi system to create the vacuum needed to ensure a reliable grip. The vacuum cup itself will either be hard (if the surface to be lifted is soft) or soft (if the surface to be lifted is hard). Vacuum cup grippers require only one surface for grasping, apply uniform pressure to the surface grasped, are relatively light-weight, and may be used on a variety of different materials.

Magnetic grippers, used to handle ferrous materials, offer several advantages over other grippers. Pickup times for a magnetic gripper are very fast. They can tolerate large variations in part size and they require only one surface for gripping. They can also handle metal parts with holes in them, a task impossible for vacuum grippers. Magnetic grippers also have certain inherent disadvantages, such as their disdain for nonferrous materials. Magnetic grippers can cause portions of the workpiece to become magnetized. Also, the magnetic field may penetrate more than one workpiece and cause them to be lifted together.

Adhesive grippers are used to grip light objects that must be grasped on only one side and that are not suitable for magnetic or vacuum grippers. A problem with adhesive grippers is that the adhesive loses its tackiness with repeated use. This problem has been overcome by feeding a continuous ribbon of new adhesive material through the robot gripper.

Other types of grippers include hooks, scoops, inflatable bladders, and other specially designed devices. These grippers have been designed for specific applications where the more common types are not suitable. For example, a bladder may be inflated in a glass jar to enable it to be sensors in an array, it is possible to detect an object's shape, location, and orientation. Tactile sensors can be mounted in a robot's grippers, in a mat near the robot, or anywhere else that is convenient.

Proximity sensors detect if another object is nearby. Range sensors have the added capability of measuring the distance to that object. These devices can be attached to the wrist or end effector of a robot to aid it in detecting workpieces or in the front, sides, and rear of a mobile robot to aid in collision avoidance. These devices can be built using optical devices (such as visible or infrared light sensors), acoustics, and electrical field techniques (similar to a metal detector), to name a few. These systems can be active or passive and can achieve remarkable accuracy.(22)

Acoustic range sensors utilizing ultrasound have been developed to the point where they can almost replace vision systems. Polaroid has developed a system using special transducers that can accurately measure distances from 0.9 to 35 feet with an accuracy of plus or minus 1%. With slight modifications, the system can measure distances as close as 4.5 inches or as far as 75 feet. Multiple frequencies are used to compensate for errors caused by differences in surface geometry and allow the system to maintain its accuracy in different surroundings.(23) With such accurate depth perception, it is possible to design a computer program to enable a robot to learn its environment. Yuval Roth-Tabak and Ramesh Jain of the University of Michigan successfully performed computer simulations of such a system designed to show that a robot with range sensors could learn and remember objects in a room in relation to the room.(24)

Voice sensors are divided into speaker-dependent and speaker-independent speech recognition. Speaker-dependent systems are capable of understanding more words than a speaker-independent system, but must be taught the user's voice. Each person's voice and speech patterns vary so widely that a robot today would have little chance of understanding more than a few commands from different people. Speaker-independent systems are limited to a few commands with words that differ significantly in phoneme classes. Although a speaker-independent system can respond to several different voices, it is easily confused by words that are not in its limited vocabulary. Its main advantages are its simplicity and low cost, it can be added with one or two chips and a few external components.(25)

Machine vision is the most complicated and expensive sensor device for a robot. The price of a relatively low-cost vision system is approximately $30,000. Current systems can detect an object, identify it in various orientations, and inspect it. Vision systems can also be used to direct the actions of a robot from positioning of its end effector to navigation. Resolution of vision systems varies, but, generally, the higher the resolution, the more expensive the system and the more computer power is needed to interpret the image. Vision systems can be used to detect range by using more than one sensor and triangulating in the same manner as human eyes. Weaknesses of current vision systems include a need for controlled lighting and a lack of color detection.(26)

Other sensors available include a wide range of electronic devices that can detect temperature, pressure, fluid flow, and more. Even a simple device such as a smoke detector can be used as a robot sensor.

Now that we have examined some of the devices available to today's robots, let's look at the robots themselves. The next sections present typical examples of the robots that exist now.

2. Industrial Robots

The most widely used type of robot today is the industrial robot. These robots come in many shapes and sizes and perform a wide variety of functions. The most common of these is the robot arm usually found in manufacturing applications. Five typical examples of this type are presented below.

The Armstar, built by Tokico America, Inc., is a $150,000 painting robot. It was introduced in 1978 and is used to spray paint, finishes, and adhesives in the automotive, electronics, appliance, and plastics industries.

It can be taught using the continuous path method, where it repeats the actions it is run through, or by the point to point method, where it's end effector takes the most direct route to the locations shown to it. The Armstar utilizes high-speed optical scanning and a combination of electrical and hydraulic power.(27)

The ASEA robot, from the ASEA Group of Vasteras, Sweden, is a more general purpose robot. It can be used to perform arc welding, deburring, gluing, materials handling, and assembly. The ASEA Model IRb 6/2 can lift 13 pounds and has a repetition accuracy of plus or minus eight thousandths of an inch and can be programmed by buttons located on it or by a joystick. The Model 60/2 can lift 132 pounds and has a repetition accuracy of plus or minus sixteen thousandths of an inch.(28)

Typical arc welding robots include the Automatix Aid 800 from Automatix and the Cyro series by Advanced Robotics Corporation. The Automatix robot weighs 770 pounds and has an 880 pound A132 controller plus welding equipment. The Cyro robot is similar except that it features adaptive control to correct the weld path. Both robots depend on the part to be welded to be correctly located each time.(29)

The Intelledex 605, built by Intelledex Corporation, is a light assembly robot built for jobs requiring high dexterity and high precision and that have a light weight load. These robots can perform such delicate tasks as placing integrated circuit chips on circuit boards. The 605 debuted in April 1984 at a cost of $48,000. It has optical sensors to detect misfeed and utilizes force sensors in its end effector. The robot monitors a pressure sensitive floor mat and a light curtain composed of photocells to insure the work area is clear for safety reasons. For component identification, the robot uses a bar code reader. The 605 also has an optional vision package that utilizes a nonstandard 6-bit converter to lower its cost. The vision package sells for $12,000 to $16,000.(30)

Lesser known industrial robots include different series made for electrical utilities to perform maintenance and inspections. These robots were originally designed for nuclear power plants to reduce the radiation risk to people, but are now being modified and expanded for use in fossil-fired plants. One of the first of these robots was Rover. Designed in 1979 by William Whittaker of Carnegie-Mellon University, it was used in the Three Mile Island incident. Remotely operated by cable, it carried instruments and attachments into areas considered to be a radiation hazard. Newer robots do maintenance jobs that were once considered extremely difficult or dangerous. Cecil cleans sludge from inside steam generators and cousin Scavenger cleans spent-fuel-pools. Robot arms have been developed to inspect and repair steam generator tubes and crawlers go inside pipes to clean and inspect. Robots have even been built to inspect and repair live power lines.(31)

Shimizu Corporation of Japan has been busy developing a new line of prototypes for the construction industry. These robots are not yet on the market, but they are in the testing stage. The first of these robots is the Fireproofing Spray Robot SSR-3. Equipped with ultrasonic sensors, this robot takes over the hazardous job of spraying fireproofing chemicals. The Steel-Beam Positioning Manipulator (Mighty Jack) looks like a beam with attachments and hangs from a crane or other machine. Operated by remote control, it can lift two or three beams at a time and assemble them faster and safer than humans can. The Radio-Control Autorelease Clamp (Mighty Shackle Ace) holds columns and beams together until they are bolted, then releases them. Manually releasing clamps of this type is considered to be a hazardous job. The Activated Concrete-Cutting Robot was designed for decommissioning nuclear power facilities. It can demolish structures that would pose a radiation hazard to human workers.

A number of other robots being developed by this company include the Ceiling Panel Positioning Robot (CFR-1), the grinding and cleaning Multipurpose Traveling Vehicle for Concrete Slab (MTV-1), the Concrete-Floor Finishing Robot (FLATKN), the Wall-Finishing Robot (OSR-1), the Spray-Coating Robot (SB MultiCoater), and the Automatic Silo-Lining System (SALIS).(32)

There are many other special applications that robots have been built for in industry. They have done everything from transporting materials in factories to cleaning ship’s hulls. Listing all the various types could provide a book in itself. The types presented here demonstrate their versatility and capabilities.

3. Security Robots

These robots are the police, the guards, and the soldiers of the robot world. This section will examine a representative sample of the various types available beginning with the Pedsco. The Pedsco, priced at $20,000 to $50,000, is a six wheeled, two armed robot built by Pedsco of Scarborough, Ontario. Its primary function is bomb disposal. It is equipped with a television camera and may carry a riot shotgun and an X-ray device. An operator controls the robot by remote control and monitors it via the television camera. This allows the operator to remain safely out of danger while the robot disposes of the bomb. This robot is also useful for performing other dangerous tasks, such as nuclear waste removal, firefighting, and riot control. The television camera also allows it to be used for the less dangerous task of surveillance.(33)

The Prowler (Programmable Robot Observer With Logical Enemy Response) was designed by Robot Defense Systems, Inc. for military and security applications. The Prowler ranges in price from $250,000 for a sentry to $500,000 for a model capable of fighting tanks. The robot resembles a ten foot long box with a sloping front and six wheels. It comes in two versions, one electric and one diesel, is armored, and carries various types of armament. It can be controlled by wire, radio, or its own semiautonomous computer. The robot is designed for reconnaissance, mine laying, decoying, search and rescue, and combat.(34)

The TMAP from Grumman looks like the Prowler's little brother. Other than a slightly smaller size and two fewer wheels, the TMAP is remarkably similar to the Prowler in appearance. Its armament, like the Prowler, consists of various combinations of missiles, guns, and grenade launchers. The major difference between the two robots is the method of control. The TMAP is controlled by a fiber optic cable that limits its range to 2.5 miles.

Another robot warrior is the Fire Ant manufactured by Sandia National Laboratories. It resembles a four wheeled all-terrain vehicle with antennas and searchlight. Although it is designed to fight enemy armor, the Fire Ant's method is significantly different from the Prowler or the TMAP. The part of the Fire Ant that resembles a searchlight is actually a huge explosive charge that not only destroys the enemy, but also the robot itself. To use the Fire Ant, a soldier must get it within 550 yards of its target. From that distance, it can detect and close with enemy armor under its own control.

The Odex, developed by Ohio State, Carnagie-Mellon, and Odetics, Inc., is a break from the previous designs' wheeled configurations. This robot can travel up to 8 miles per hour on six articulators (legs). It is microprocessor controlled, can carry one ton (five times its own weight), can climb stairs, and can go over obstacles up to 33 inches high. In its present configuration, the Odex is unarmed. It is being used to study its ability to cross terrain that is unaccessible to wheeled vehicles.

The Air Force, concerned about maintaining its runways and servicing its aircraft in a chemical or other hostile environment, is experimenting with a robot of its own. Marvin is a 51 inch tall robot that resembles a human with wheels. It has plastic skin and an internal computer and can turn its head, move its arms, grasp and lift, and roll on its wheels. It is designed to repair runways, fight fires, and repair, refuel and rearm aircraft. Six robots will work independently under the supervision of one operator who will only interfere in case of trouble.

The Navy is developing its own version called Robart II. Robart II is designed to detect smoke, fire, compartment flooding, and hazardous gases. It will also be used to detect intruders whether on ship or shore. It will be equipped with infrared sensors and a voice synthesizer to enable it to detect and interact with humans. The present level of development of these last two robots is not currently available.(35)

4. Explorers

This type of robot often makes the news even though only small numbers of them have ever existed. They are usually found exploring other planets or under the oceans.

Among the first space-faring robots were Surveyor 3 and Surveyor 5. Both were launched in 1967 and landed on the moon. Surveyor 3 used a metal claw to dig trenches and test the moon's surface while Surveyor 5 scooped up soil and performed a chemical analysis. Other members of the Surveyor family did not fit the definition of a robot established earlier in this paper because they did not transport a payload or have a manipulator.

The following year, 1968, the Soviet Union launched the Zond 5. The Zond 5 carried a payload of biological experiments and turtles around the moon and returned to Earth. Two years later, the next space-faring robot, also a Soviet craft, was the Luna 16. The Luna 16, launched in 1970, landed on the moon, collected a core sample of soil, and returned to earth.(36)

Probably two of the most famous robots ever launched were the Viking 1 and Viking 2. Launched in 1975, they landed on Mars in 1976 and began the first exploration for extraterrestrial life. Both had mechanical arms that scooped up and tested the Martian soil. Analysis of the soil and other experiments performed by the Vikings showed strong evidence of life, but could not conclusively prove that it existed on Mars.(37)

Other space vehicles and rovers have been launched over the years. Some were called robots and some were not, depending on the definition of robot then in use. A closer look at these vehicles would enable one to establish a fitting name and definition for them. However, that project is outside the scope of this paper.

Underwater robots are the explorers we send to investigate our ocean depths. They generally bear some resemblance to a minisub and are remotely controlled. Developed by the Naval Ocean Systems Center, the Cable-controlled Underwater Recovery Vehicle (CURV III) can operate at depths of nearly 10,000 feet. This robot, which resembles a high-tech sleigh, has a single manipulator and can perform underwater inspection, ocean engineering, search missions, and salvage and recovery operations.(38) A civilian robot with similar abilities, Jason, recently was used to recover artifacts from a fourth century Roman shipwreck and to explore for undersea volcanic vents.(39) Other such robots have been used successfully to search for such famous shipwrecks as the Titanic and the Edmund Fitzgerald.

5. Demonstration/Hobby Robots

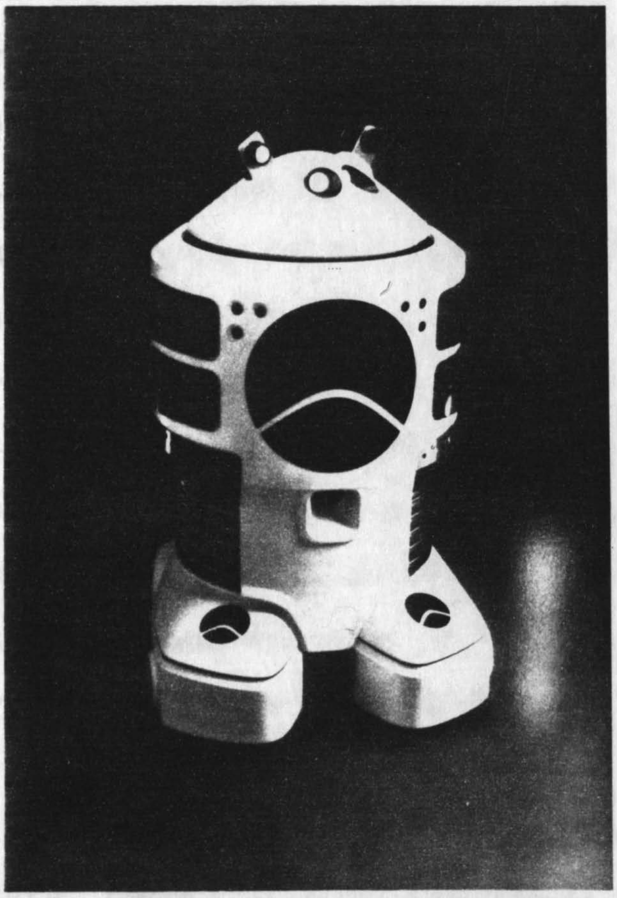
Demonstration and hobby robots are the one of a kind type built by various companies or individuals to show off their expertise. The ones built by companies are usually expensive and complex and are built to demonstrate the technology, hence the term "demonstration robot." The company that builds one usually hopes that it will one day be the basis for a commercially successful model.(40) Hobby robots are built by individuals either to show what they can accomplish or because they simply want to enjoy building and having a robot. Particularly good and inexpensive designs of hobby robots sometimes appear in books and articles along with the plans to build one of your own, such as the Questor in Build a Remote Controlled Robot for Under $300.(41)

6. Domestic Robots

Domestic robots are robots built for the home. While most people think of a domestic robot as a butler or maid, a domestic robot can also be a worker around the yard or where ever else you wish to use it. Extensive research has revealed two types of domestics which will soon be on the market, even though neither is a true robot by the definition presented earlier. However, since they are likely to be the only competition for the domestic market, they will be presented here.

The first is a device called the Lawn Ranger. It is a computer controlled lawn mower built by Technical Solutions of Damascus, Maryland. It will sell for $1000 to $2000 when it is marketed next year. The Lawn Ranger is a 125 pound all electric device that uses a patented optical system to seek out uncut grass and to avoid obstacles. The Lawn Ranger has a remote control that is used to steer the mower around the yard the first time. After that, it will stay within the newly cut area and look for taller grass to cut. The Lawn Ranger is not the first automated lawn mower. An earlier company marketed one named Mobot that randomly searched for grass to cut. It detected a buried cable in the yard to define its boundaries. It is hoped that the improved technology of the Lawn Ranger will improve its chances for commercial success.(42)

The second device is being advertised as a robot even though it does no physical work. It is being built by a new company called SynPet Personal Electronic Technologies located in Boise, Idaho. This device is named Newton and is basically a personal computer, a mobility system, and a number of interface devices all built into one package. It stands 34 inches high and resembles a cross between R2D2 of *Star Wars* and Robot of *Lost in Space*. Newton is capable of such functions as speaker dependent voice recognition, monitoring security systems, and making phone calls. Its brain is an IBM compatable computer with hard and floppy disk drives. Newton uses ultrasonics to detect motion, obstructions, and drop offs. Infrared sensors are used to detect the presence of humans. Newton is also equipped with light, smoke, temperature, and sound sensors. With its



Domestic robots include Newton. (Photo reproduced with permission of Synpet Personal Electronic Technologies.)

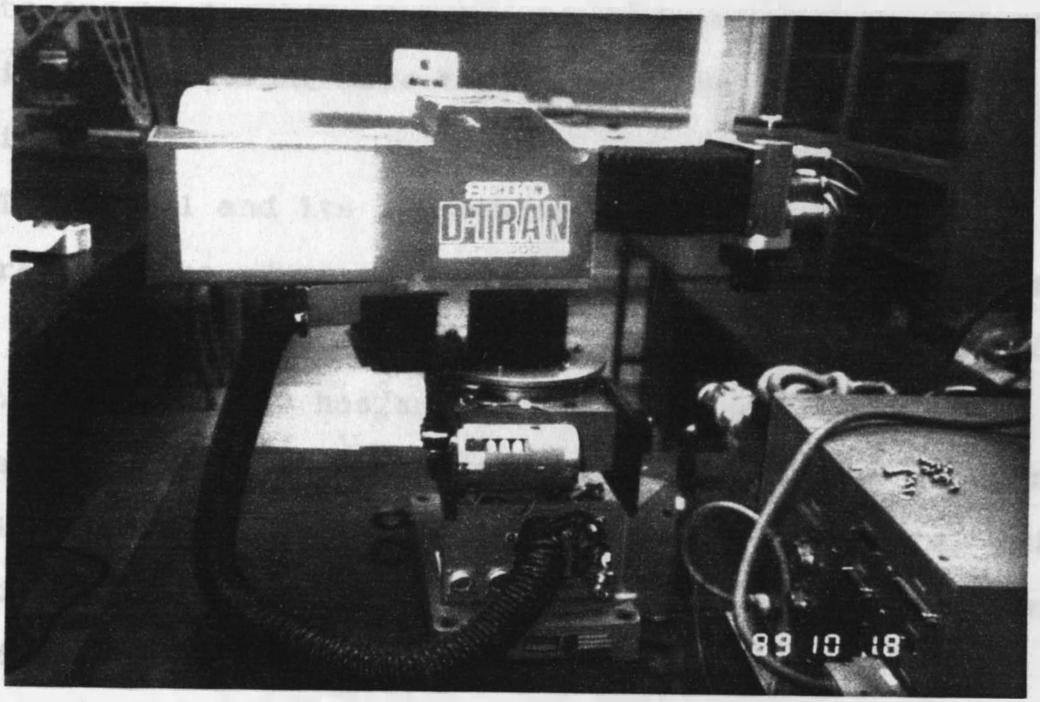
Figure IV-1. A Domestic Robot

wireless interface, it can control lights, appliances, security systems, heating, and air conditioning. Newton can be controlled by voice, programmed instructions, and remote. It uses a rechargeable power source and can find and plug in to its own recharger. Newton is scheduled to be on the market in March of 1990 and will sell for $7995.(43)

Newton is not an original idea, but an updated version of an old one. A company called Hubotics, Inc., located in Carlsbad, California, produced a robot named Hubot as late as 1985. It resembled a computer terminal mounted on top of a rolling stand. It had a 128K Random Access Memory (RAM), a floppy disk drive, a 12 inch black and white television, a radio, a cassette tape deck, an ATARI video game recepticle, a voice synthesizer and recognition circuit, an obstacle avoidance system, and a rechargeable power supply. Options included a voice command telephone dialer, a remote appliance control system, and a Sentry package to control lights and thermostats, detect fire or intruders, and dial for help. Also available was an automatic battery charger, a vacuum attachment, and an arm. the basic model sold for $3495 and a fully loaded model was $6000.(44)

7. Educational

Educational robots are built for the purpose of teaching people about robots through experience. They usually have features that are scaled down from the commercial models, but are controlled and respond in a similar manner. These



(a). Seiko D-Tran

(b). Heathkit Hero 1

Figure IV-2. Educational Robots

robots are true robots capable of performing work, but their physical limitations make them impractical for most applications.

The HERO 1 and its replacement, the HERO 2000, are general purpose educational robots from Heathkit. They are both programmable mobile robots capable of obstacle avoidance. The HERO 2000 has an arm that is a miniature of an industrial type with touch sensors built into its grippers. It also carries sensors to detect light, temperature, and sound and a voice synthesizer to generate speach, music and sound effects. It can be controlled and programmed by a separate wireless keyboard and can be equipped to recharge itself automatically.(45) A fully equipped HERO 2000 kit sells for $2999.95.

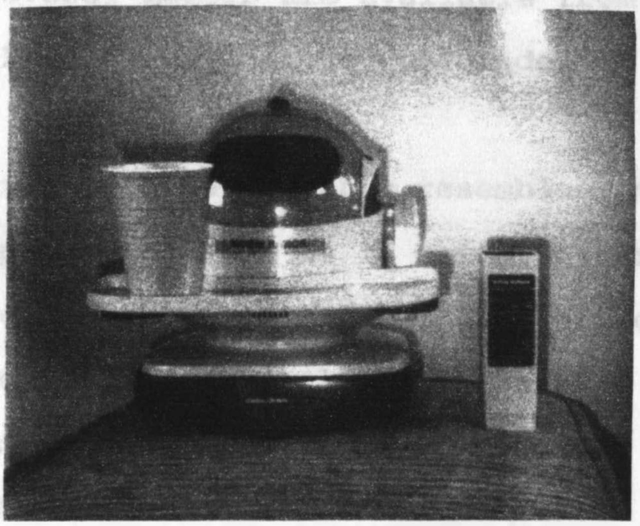
Also available from Heathkit is the robot arm trainer EWS-19-32. It uses an arm similar to the HERO 2000 and is designed for teaching about industrial robots. The kit sells for $995 and a fully assembled model sells for $1995.

A number of other companies sell educational robot arms, such as the Seiko D-Tran RT 2000. Some companies sell educational robot arms for industry specifically for testing programs before they are fed into their larger models. Educational robots of various types may be obtained to imitate most applications found in industry.

8. Toy Robots

Toy robots are sold by electronics and toy companies

(a). More than a showbot, this robot has functional arms. (Photo courtesy of David Simpson.)



(b). This toy robot can perform extremely light work.

Figure IV-3. Showbot and Toy Robot

everywhere. Some of them can actually function as a real robot, but they are usually extremely limited by size and strength. Some of the more complex ones may have radio or ultrasonic control and may be able to perform complicated arm and manipulator movements. Examples of these types are the Radio Shack Robie series and Armatron series. The larger toy robots are usually the nearest type to a domestic that is available to the consumer.

9. Showbots

Showbots are not true robots. They are designed to give the appearance of a robot while an operator remains hidden and controls their actions. They are used for entertainment, advertisement, or as showpieces. In spite of their limited usefulness, several models are available from such companies as The Robot Factory of Cascade, Colorado.

10. Simulacra

A **simulacrum** is a device that resembles another form in function or appearance.(46) It is a fair description of a new type of device that has been labeled "robot." This device is an electromechanical imitation of a form of life.

A specific example of a simulacrum is the new European made "robot" bee. This device was constructed to imitate the dance-language of bees to enable scientists to test the bees' communication abilities. The "bee" portion of this device is attached to a larger mechanism that controls it and allows the scientists to program its every move. This device enabled scientists to prove that sound was a component of the bees' language and was successfully used to send the bees up to a mile away to specific locations in search of food.(47)

11. Summary

Robots exist throughout our society performing a myriad of tasks. They can be built to handle complex tasks that once could only be performed by humans and many that humans cannot. They continue to expand into new areas whenever they prove themselves to be economically feasible. Yet, with all the types available, the average consumer cannot buy a practical robot for our own use. The Synpet robot, Newton, is too expensive and sophisticated for most Americans and it lacks the ability to do physical work. The Lawn Ranger, if it proves to be practical, is limited to one specific task. What is needed is an inexpensive robot that is easy to operate and can perform useful labor about the home. The Simplified Control Multipurpose Robot (SCMPR or SCaMPeR) is developed in the remainder of this paper to fulfill this need.

END NOTES

(1)Isaac Asimov, I, Robot, (Garden City, New York: Doubleday and Company, Inc., 1950).

(2)David R. Shircliff, Build a Remote Controlled Robot for Under $300, (Blue Ridge Summit, Pennsylvania: Tab Books, Inc., 1986), xi.

(3)Anne Cardoza and Suzee J. Vlk, Robotics, (Blue Ridge Summit, Pennsylvania: Tab Books, Inc., 1985), 1.

(4)Ibid., 2.

(5)Pamela B. DeVinne, ed., The American Heritage Dictionary, 2nd College Edition, (Boston, Massachusetts: Houghton Mifflin Company, 1985), 1067.

(6)Ibid.

(7)Philip Babcock Gove, Ph. D., ed., Webster's Third New International Dictionary of the English Language Unabridged, (Springfield, Massachusetts: G. & C. Merriam Company, 1976), 1964.

(8)Edward L. Safford Jr., Handbook of Advanced Robotics, (Blue Ridge Summit, Pennsylvania: Tab Books, Inc., 1982), 3.

(9)Ivan G. Stearne, How to Design/Build Remote Control Devices, (Blue Ridge Summit, Pennsylvania: Tab Books, Inc., 1981), 9.

(10)Cardoza and Vlk, Robotics, 2.

(11)David F. Tver and Roger W. Bolz, Robotics Sourcebook and Dictionary, (New York, New York: Industrial Press, 1983), 115.

(12)Marvin Minsky, ed., Robotics, (Garden City, New York: Anchor Press/Doubleday, 1985), 190.

(13)Geoffrey L. Simons, Is Man a Robot?, (Chichester, West Sussex, U.K.: John Wiley and Sons, 1986).

(14)Safford, Handbook of Advanced Robotics, 20.

(15)Jack Williamson, The Humanoid Touch, (New York, New York: Holt, Rinehart, and Winston, 1980).

(16)Malcolm Plant, Dictionary of Space, (Harlow, Essex, U.K.: Longman Group Limited, 1986), 53.

(17)Harley Shaiken, Work Transformed: Automation and Labor in the Computer Age, (New York, New York: Holt, Rinehart, and Winston, 1985), 156.

(18)Ibid., 162-163.

(19)Ibid., 168.

(20)Committee for Economic Development, Work and Change: Labor Market Adjustment Policies In a Competitive World, (New York, New York: Committee for Economic Development, 1987), 17-18.

(21)Mikell P. Groover and others, Industrial Robotics: Technology, Programming, and Applications, (New York, New York: McGraw-Hill Book Company, 1986), 116-139.

(22)Ibid., 147-155.

(23)Polaroid Corporation, Ultrasonic Components Group, Ultrasonic Ranging System, (Cambridge, Massachusetts: Polaroid Corporation, September, 1987), 28; "Near Range Extender Modification," Polaroid Ultrasonic Ranging System Handbook Application Notes/Technical Papers, (Cambridge, Massachusetts: Polaroid Corporation, (date unknown)); "Ranging Beyond 35 Feet," Polaroid Ultrasonic Ranging System Handbook; C. Biber and others, The Polaroid Ultrasonic Ranging System, (New York, New York: Audio Engineering Society, October 31, 1980), 4, 1696(A-8).

(24)Yuval Roth-Tabak and Ramesh Jain, "Building an Environment Model Using Depth Information," Computer, June 1989, 85-90.

(25)Archer Semiconductor Reference Guide, 1989 ed., (Fort Worth, Texas: Radio Shack, A Division of Tandy Corporation, 1988), 68-70.

(26)Groover and others, Industrial Robotics, 160-184.

(27)Cardoza and Vlk, Robotics, 28-29.

(28)Ibid., 32-33.

(29)Ibid., 39-43.

(30)Ibid., 49-52.

(31)Greg Paula, "Robotics: Growing Maintenance Option for Utilities," Electrical World, May 1989, 65-72.

(32)Roozbeh Kangari and Tetsuji Yoshida, "Prototype Robotics in Construction Industry," Journal of Construction Engineering and Management, vol. 115, no. 2 (June 1989), 284-301.

(33)Cardoza and Vlk, Robotics, 64-65.

(34)Ibid.

(35)Bill Siuru, "Robo Warriors," Mechanical Engineering, May 1989, 82-87.

(36)The New Encyclopedia Britannica, 1982 ed. s.v. "Space Exploration."

(37)Tony Osman, Space History, (New York, New York: St. Martin's Press, 1983), 115-117.

(38)Cardoza and Vlk, Robotics, 79-81.

(39)Diane Herbst, "In the Wake of a Modern Jason," Oceanus, vol. 32, no. 2 (Summer 1989), 84-87.

(40)Safford, Handbook of Advanced Robotics, 45-71.

(41)Shircliff, Build a Remote Controlled Robot for Under $300.

(42)Bill Evans, "The Lawn Ranger," Mechanical Engineering, June 1989, 142.

(43)SynPet Personal Electronic Technologies, The Anatomy of Newton, (Hollywood, California: Bear Advertising, 1989); Synpet Personal Electronic Technologies, Boise, to Terry Neville, Brookings, 31 October 1989.

(44)Cardoza and Vlk, Robotics, 46-49.

(45)Veritechnology Electronics Corporation, Heathkit/Zenith Educational Systems Division, "HERO 2000: The Knowledge Builder," Heathkit/Zenith Educational Systems, (St. Joseph, Missouri: Veritechnology Electronics Corporation, date unknown).

(46)DeVinne, ed., The American Heritage Dictionary, 1142.

(47)Weiss, Rick, "New Dancer in the Hive," Science News, vol. 136, no. 18 (28 October 1989), 282-283.

II. DESIGNING A DOMESTIC ROBOT (SCMPR)

A. Establishing Design Criteria

The robot to be described is a multipurpose robot with a simple control system. From this point on, it will be referred to by the name given to the actual prototype, the Simplified Control Multipurpose Robot, by its initials, SCMPR, or by its acronym, SCaMPeR. Essential design information is presented, however, complete design details are not included.

Before designing a domestic robot, it is necessary to decide what tasks it is to perform. Because sophisticated electronic or mechanical devices tend to be expensive, the robot should be built as simply as possible. Since a simple robot cannot perform particularly complex tasks, it should have the strength to do hard labor to make it useful. The robot brain must be able to perform adequate functions to give the robot an edge over manually operated equipment, but still must be inexpensive and easy to operate. To achieve this, the robot should be able to operate semi-autonomously and yet have remote control capabilities to allow it to perform functions beyond the abilities of its brain. Given these restrictions, possible tasks for the robot would include hauling heavy weights, pushing or pulling attachments, and providing a mobile power source.

The robot described so far would be most useful outdoors. The tasks it could perform would be comparable to a robot garden tractor, though a smaller version could do lighter tasks indoors. The robot would have to be able to negotiate turf typically found in yards and gardens, such as grass, mud, snow, and ice, as well as sidewalks and roads. It should be able to carry a load normally considered too heavy for a person (the target load for SCMPR is 200 pounds) and be able to follow where ever he/she decides to go. Its travelling speed should approximate a human walk and it should have the endurance to work all day. It should have safety devices built in to help prevent it from running into or over an object and it should be durable enough to survive occasional accidents. Also, since people go outdoors regardless of the weather, it should be weatherproof.

B. Design Options

The following paragraphs give some of the options available to meet the criteria listed and briefly discuss each. They have been separated into three general areas: the body, the drive system, and the brain.

The body is the most important part of the robot. It must be designed to allow the robot to perform its function and to provide a base to which the drive system and the brain can be attached. Since the primary function of SCMPR is to haul heavy loads, the body should be designed to carry a box or platform for the load. Since the design is to be kept simple, the body should be kept low to the ground for stability. In order for the robot to be able to operate in areas where people function, it must be narrow enough to enable it to fit through doors. Also, the shape of the body must provide a location suitable for sensors.

The drive system is the next consideration. Four options are considered here: legs, tracks, wheels, or a combination of two of these. Legs are capable of providing mobility over more types of terrain than the other options, but they present several difficulties. The first problem is stability. This problem could be partially overcome by using a six legged system with three legs always on the ground. However, the robot would have a tendency to bounce or vibrate when moving quickly. The next problem is the complexity of such a system. The legs would have to be carefully synchronized with gears, electronics, or both. Add to this a system for turning and the robot quickly becomes very complicated and expensive.

Tracks are the next best system for moving over rough terrain. They can be easily controlled and provide a reliable method of moving the robot. Their main drawback is their expense. Tracks that would be suited for a robot are commercially available for different models of snowblowers. Due to the length of these tracks, a robot over two feet long would most likely require two pairs, one for the front and one for the rear. Price estimates for two different models of snowblower tracks with the necessary wheels and hardware ranged from $140 to $383 per pair or $280 to $766 per robot. Also, because of the length of a four track robot and the hard wheels used with the tracks, a suspension system would need to be added to eliminate vibrations and to allow the robot to negotiate bumps and dips.

Wheels cannot travel over rough terrain as well as legs or tracks, but they are much less expensive. Traction can be increased by using more wheels and by linking their drives together. The need for a suspension system can be eliminated by using pneumatic tires and adjusting the air pressure. The wheels can be made to steer like an automobile or by the skid steer technique.

Various combinations of drive systems offer different advantages and disadvantages. A system with two legs in front and either wheels or tracks in back would be able to handle some obstacles that tracks or wheels alone could not, but it would still be a complex and expensive system. Using wheels in front and tracks in back gives more traction than a wheeled system and is less expensive than a tracked system, but may not give enough improvement in performance to justify the cost over a wheeled system.

There are two practical options for the brain of SCMPR. One, used in industrial robots, is to use a microprocessor and program its responses. The other is to use a system similar to the one being developed at the Massachusetts Institute of Technology (MIT). Rodney Brooks, director of the mobile-robots group at MIT's Artificial Intelligence

Laboratory, has been developing small robots that react similarly to insects. He has accomplished this by building brains that use layered responses. Instead of a computer with a single program that can crash the whole system, his robots have circuits built for various reactions to the sensor inputs. If one portion of the brain fails to respond properly, it does not affect the rest. By having his robots react to their environment instead of running a program to make decisions, he has been able to create amazing simulations of insect life and has built robots that can react to their environment and survive outside the laboratory.(1)

END NOTES

(1)Fred Hapgood, "Artificial Intelligence," Omni, vol. 11, no. 1 (October 1988), 38, 173.

III. CONSTRUCTION OF SCMPR

A. Building the Body

A prototype of SCMPR was constructed to demonstrate its practicality and to provide information about the performance and the cost of such a robot. For simplicity's sake, the body was modeled after a truck with a box on the back and a head where a cab would be. The head provides a place to mount sensors and provides protection for the electronic circuits. Sufficient room was left below the box for a power source. While other shapes may also have functioned as well, this design met the needs of the robot and provided an overall appearance of familiarity.

The wheeled system was selected for SCMPR because of its simplicity and cost. It provides a workable system to prove the robot's abilities and a starting point for experimentation. Pneumatic tires were used to eliminate the need for a suspension. To increase the traction, the three wheels on each side were linked together with chains. Steering is accomplished by using a skid steer system with an independent motor for each side. The motors to drive the wheels are designed for an electric wheelchair. They were selected because an electric wheelchair carries the same load and travels the same speed as those chosen for SCMPR. The motors are 24VDC and require two deep cycle batteries (marine batteries were used) which also power the brain. The turn ratio of the motors was high enough compared to the wheels

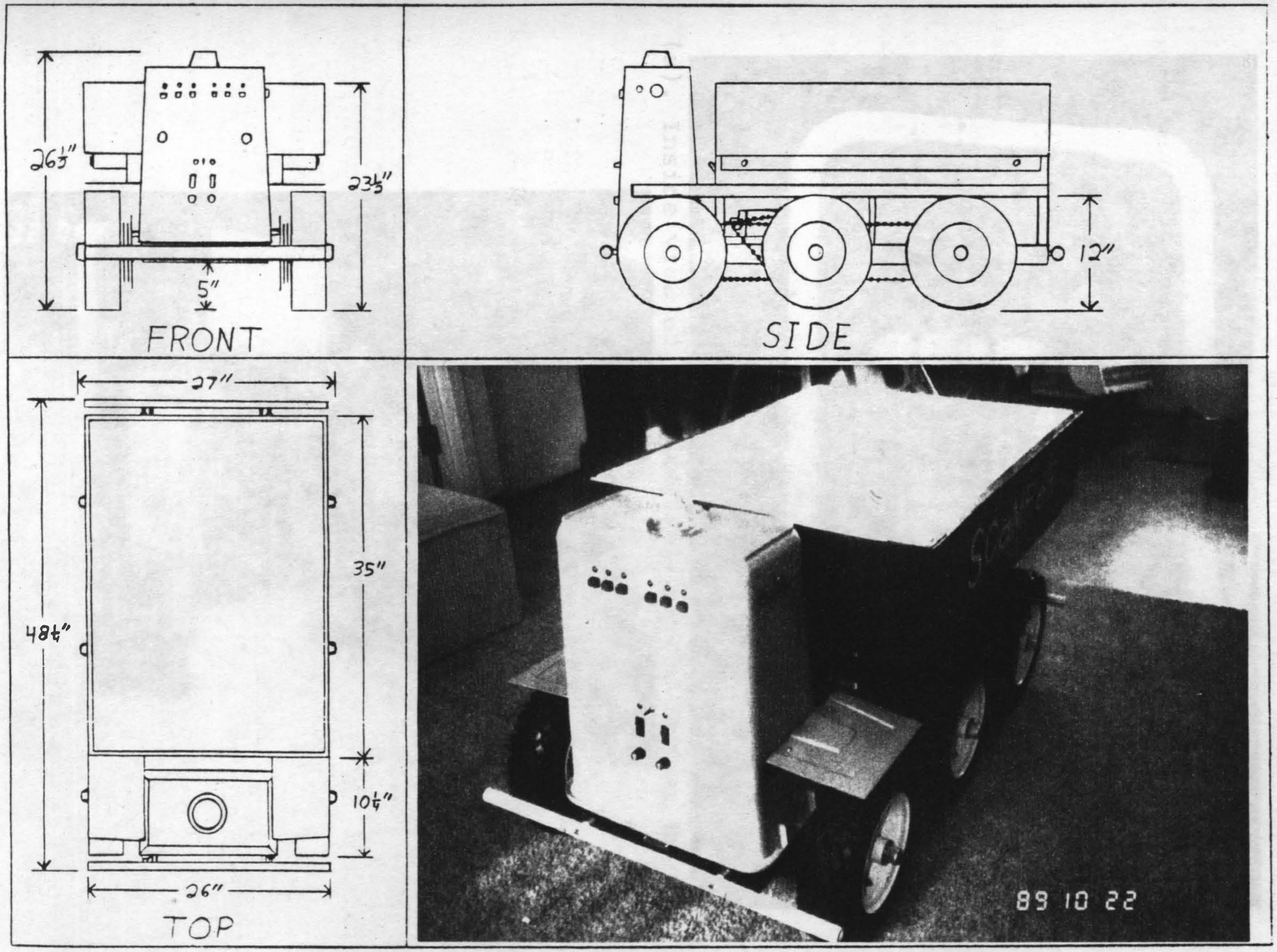
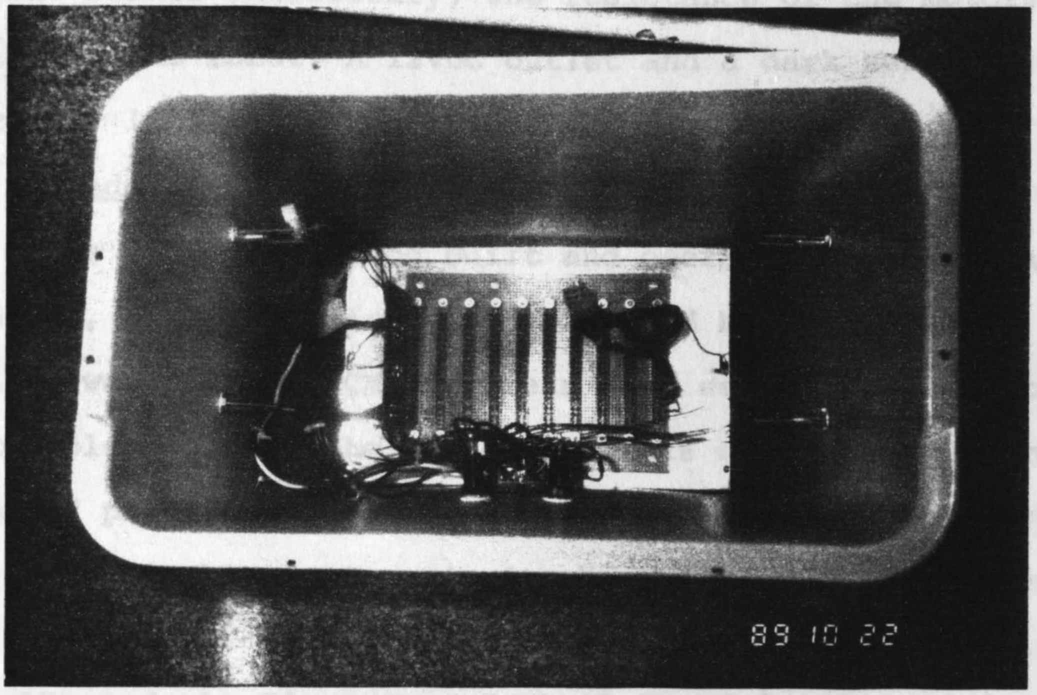


Figure VI-1. SCaMPeR Shown With Dimensions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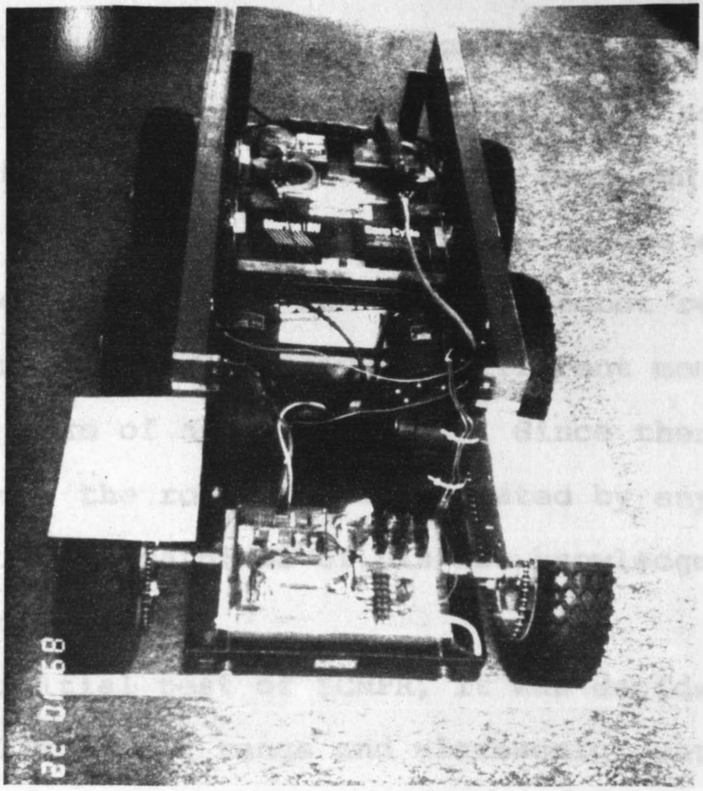
(a). Inside view of the head showing the Mother Board.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(b). View of chassis minus the head and box.

Figure VI-2. SCaMPeR Inside View

to make brakes unnecessary, the resistance of the motors will stop the robot. A 12VDC outlet and a dark sensing emergency light were added to the head.

B. Adding the Brain

Since SCMPR was to be built and operated as simply as possible, a modification of the layered brain discussed earlier was chosen. SCMPR's brain is a series of separate boards plugged into the connector slots of a mother board in order of priority. A board plugged into a higher priority slot will disable lower priority boards when it is activated. For example, if the Radio Control Board is plugged into slot two and the Ultrasonic Control Board is plugged into slot three, turning on the Radio Control Board will disable the Ultrasonic Control Board whether it is turned on or not. A memory board could be placed in slot four and then be overriden by either remote. This system allows a device to be added to detect objects and stop the robot regardless of its current mode. It also allows a different mode to control the robot in case of a board failure. Since there is no microprocessor, the robot can be operated by anyone who can turn on a switch regardless of his/her knowledge of electronics or computers.

For the initial test of SCMPR, it was decided to give it radio control for long range and ultrasonic control for short range and a follow mode. In the follow mode, SCMPR will follow a signal from the ultrasonic transmitter. The transmitter may then be clipped to a belt worn by the operator. The Mother Board was given ten slots, the first of which is required by the Control Board, so seven slots and several outputs are still available. Possible boards for the remaining slots are memory, range and obstacle detection, voice control, microprocessor control, line following control, wire following control, and/or control boards for attachments such as a robot arm or an automatic hitch.

To make it easier to expand SCMPR, it has a six output power supply. It supplies 5V, 6V, 9V, 15V, and two variable DC voltages to the Mother Board. The 5V and 15V supplies were chosen because they are standards for most integrated circuits. The 6V and 9V supplies were chosen to allow circuits intended for battery power to be used. The variable supplies allow unusual voltages and may be adjusted to another supply's voltage to provide an alternate source or to prevent an overload on one supply.

Schematics for SCMPR are shown from Figure VI-3 to Figure VI-12. Figure VI-3 represents the complete chassis of the robot with the connections shown to the Motor Drive Board, the Power Supply Board, and the head. Figure VI-4 is the Power Supply Board with inputs and outputs identified. Figure VI-5 shows the Motor Drive Board with the inputs from the Mother Board of the head and the outputs to the drive and reverse relays. Also shown on the Motor Drive Board is the motor disable circuit that connects to the bumpers to stop the robot when the bumpers are pressed. Figure VI-6 shows the head. Included in the head are the Emergency Light Board, the 12V outlet, switches, and connections to the Mother Board. Figure VI-7 is an illustration of the interconnections made by the Mother Board. Jack J-4 represents the unused output connections available for expansion. The Control Board, Figure VI-8, plugs into the Mother Board and provides connections for the priority relays of the following boards, the reset to the Motor Drive Board, and the LED indicators of unused switches on the head. The Radio Control Board, Figure VI-9, converts the digital outputs from a hobby radio receiver to analog signals for the Motor Drive Board. The radio used is a standard two channel digital AM hobby radio of the type that can be purchased at any radio control (R/C) hobby store. Figure VI-10 is the Ultrasonic Control Board. Its circuit was modified from a Radio Shack Robie Junior toy robot.

Immediately following the schematics are the parts lists for SCMPR. The prices listed are retail and are higher than those that a manufacturing company would pay. The Ultrasonic Sensor Boards and the Ultrasonic Transmitter prices listed are for equivalent replacement parts.

The finished robot is 48 1/2 inches long, 27 inches wide, 26 1/2 inches tall, and weighs approximately 200 pounds.

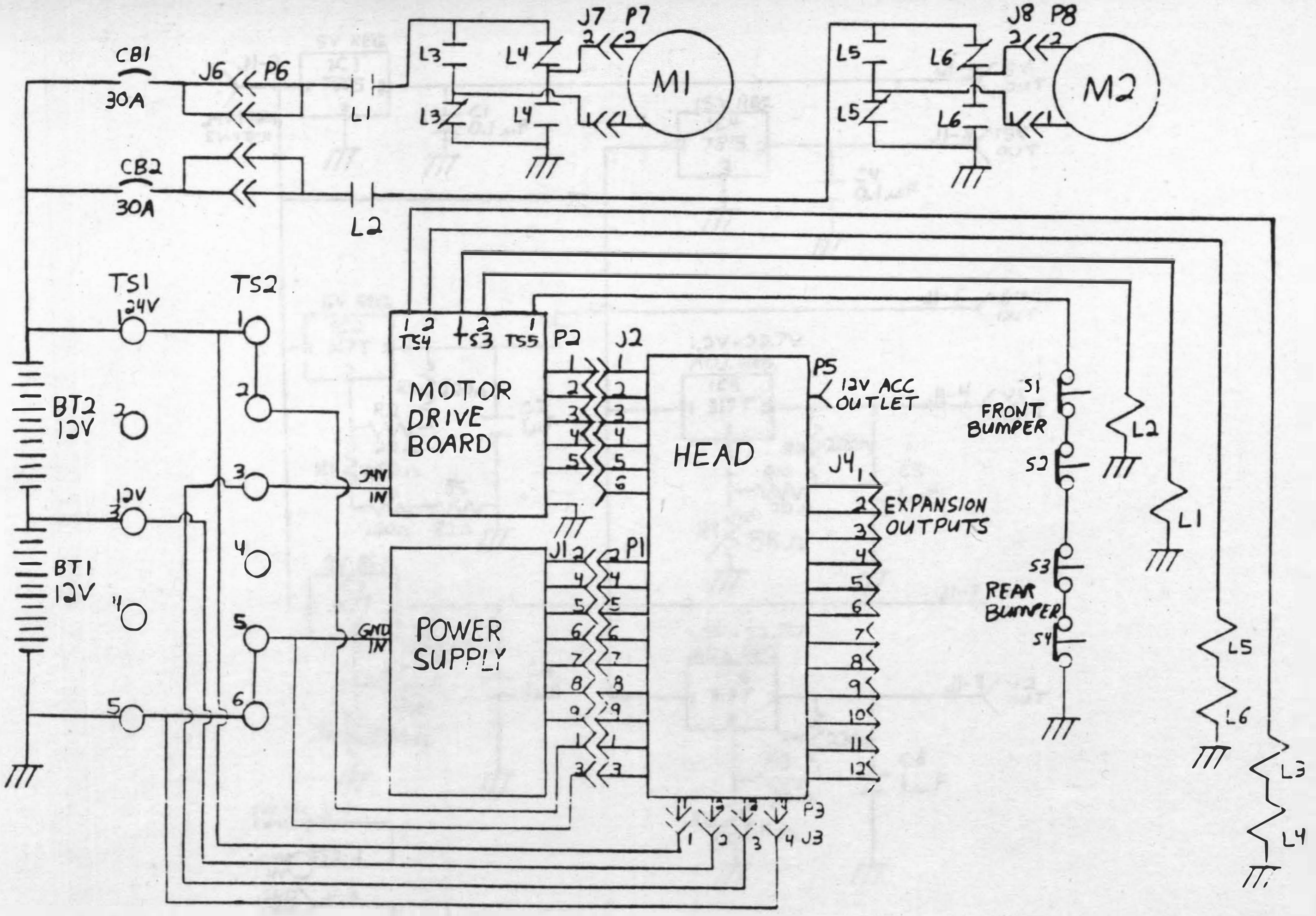

Figure VI-3. Chassis Schematic

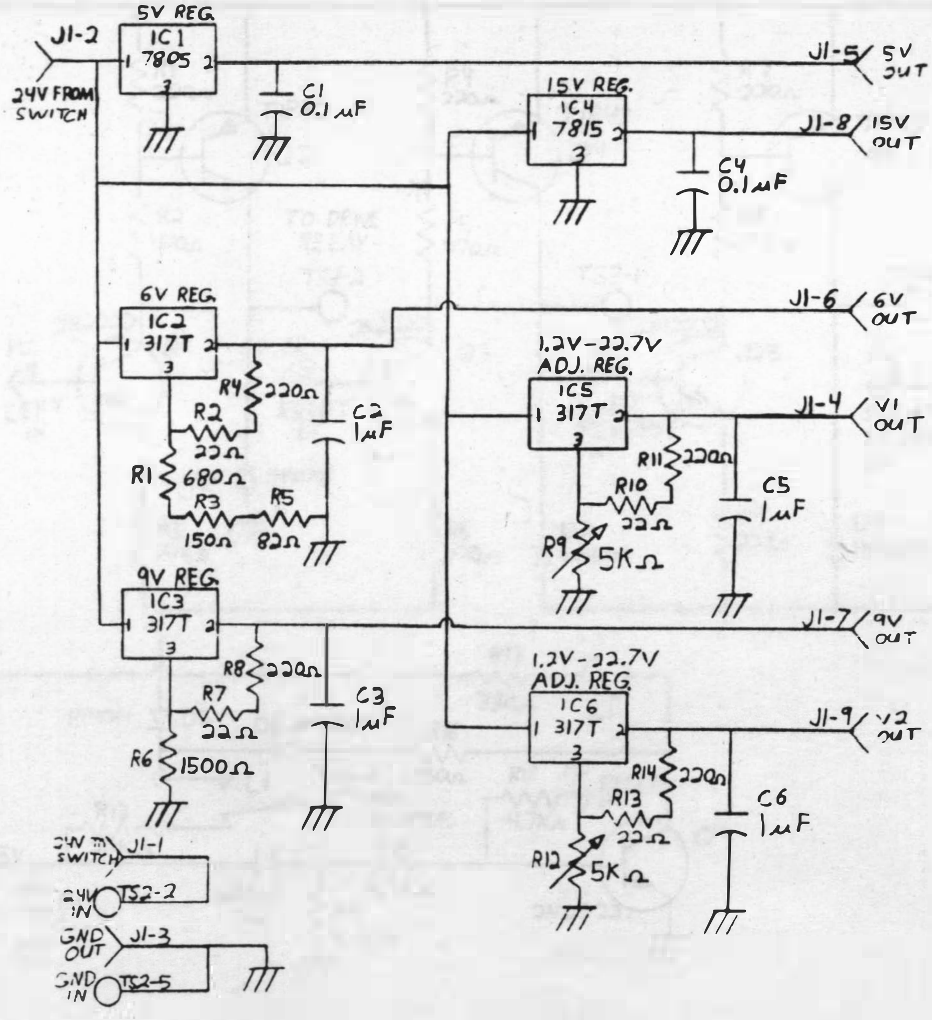

Figure VI-4. Power Supply Board Schematic

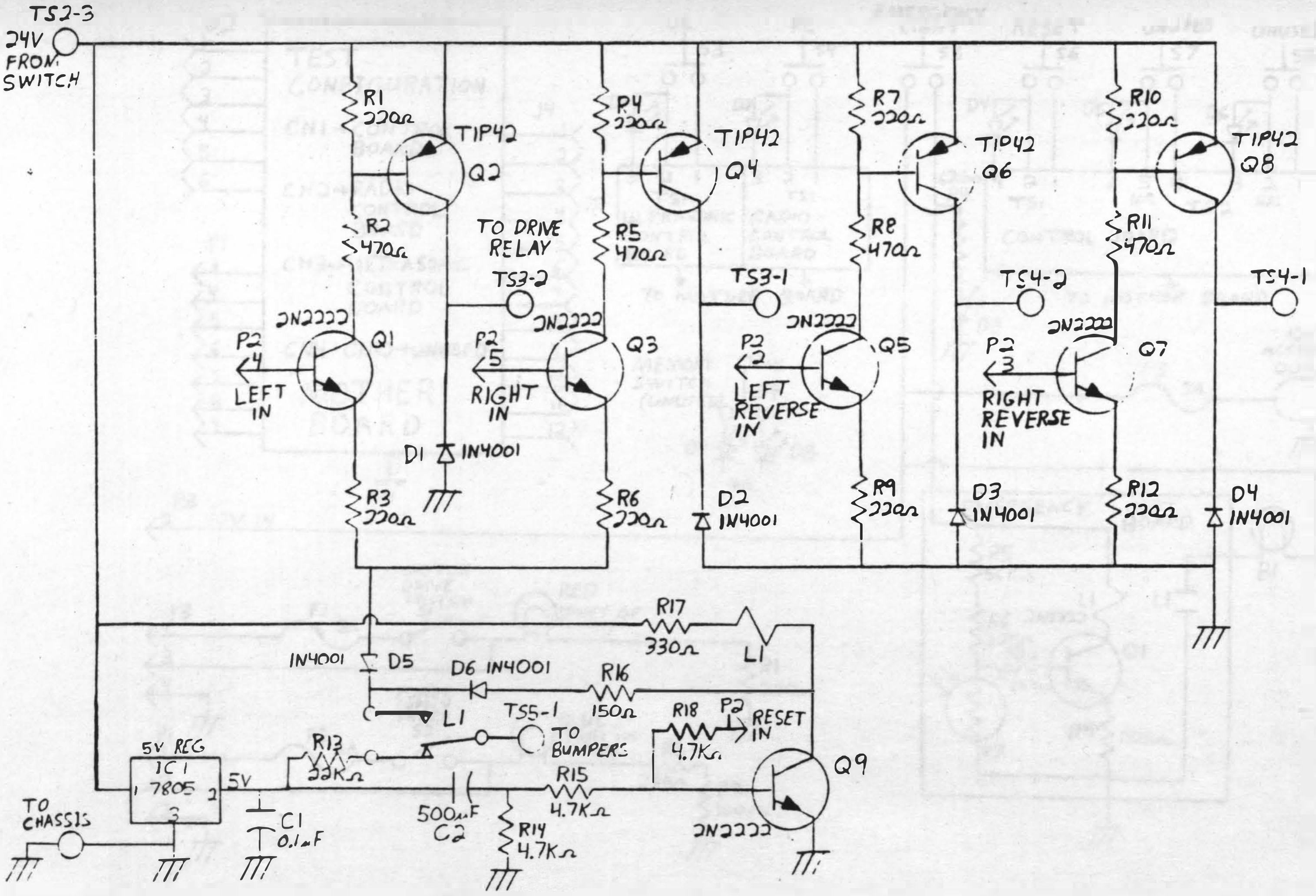

Figure VI-5. Motor Drive Board Schematic

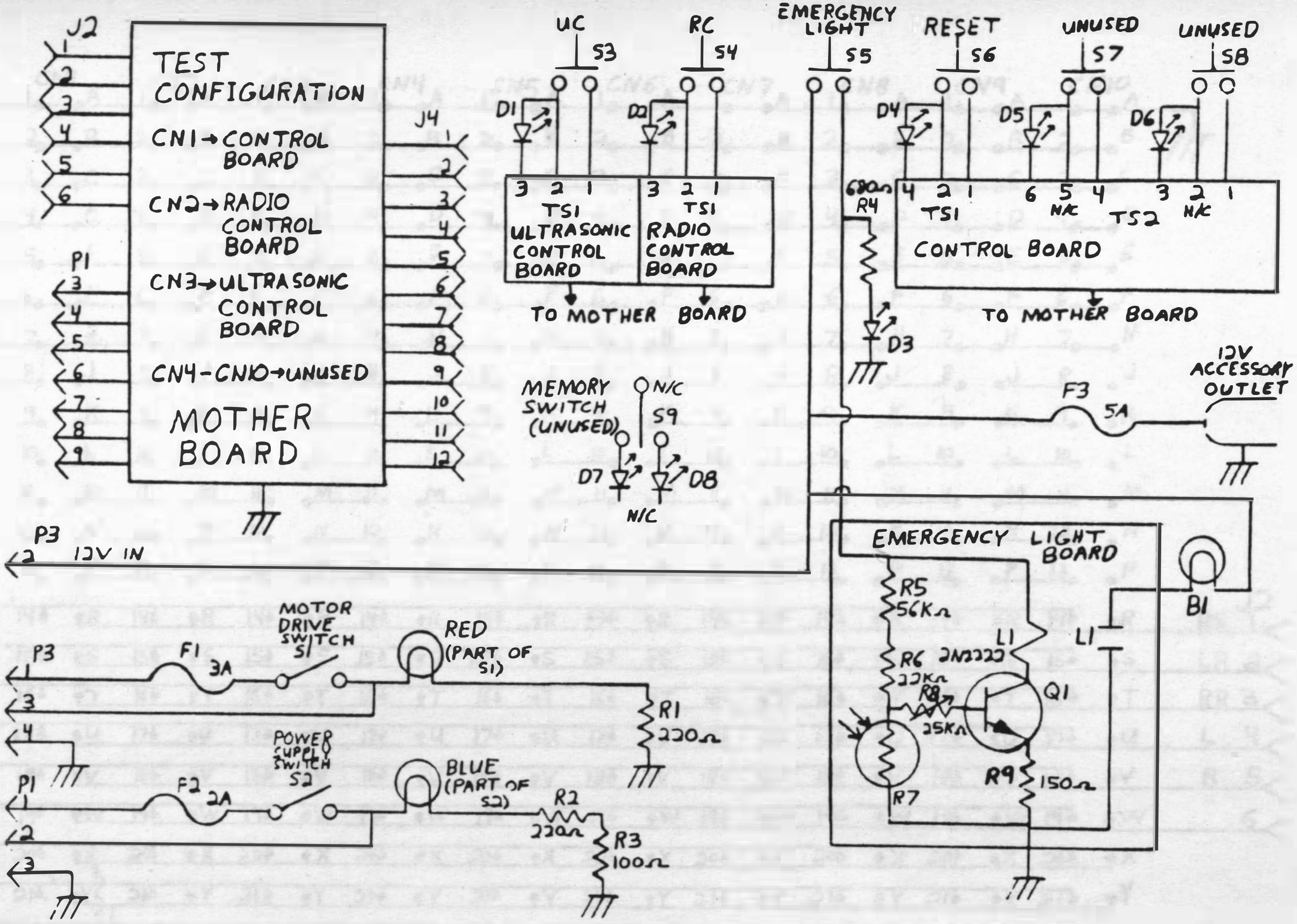

Figure VI-6. Head Schematic

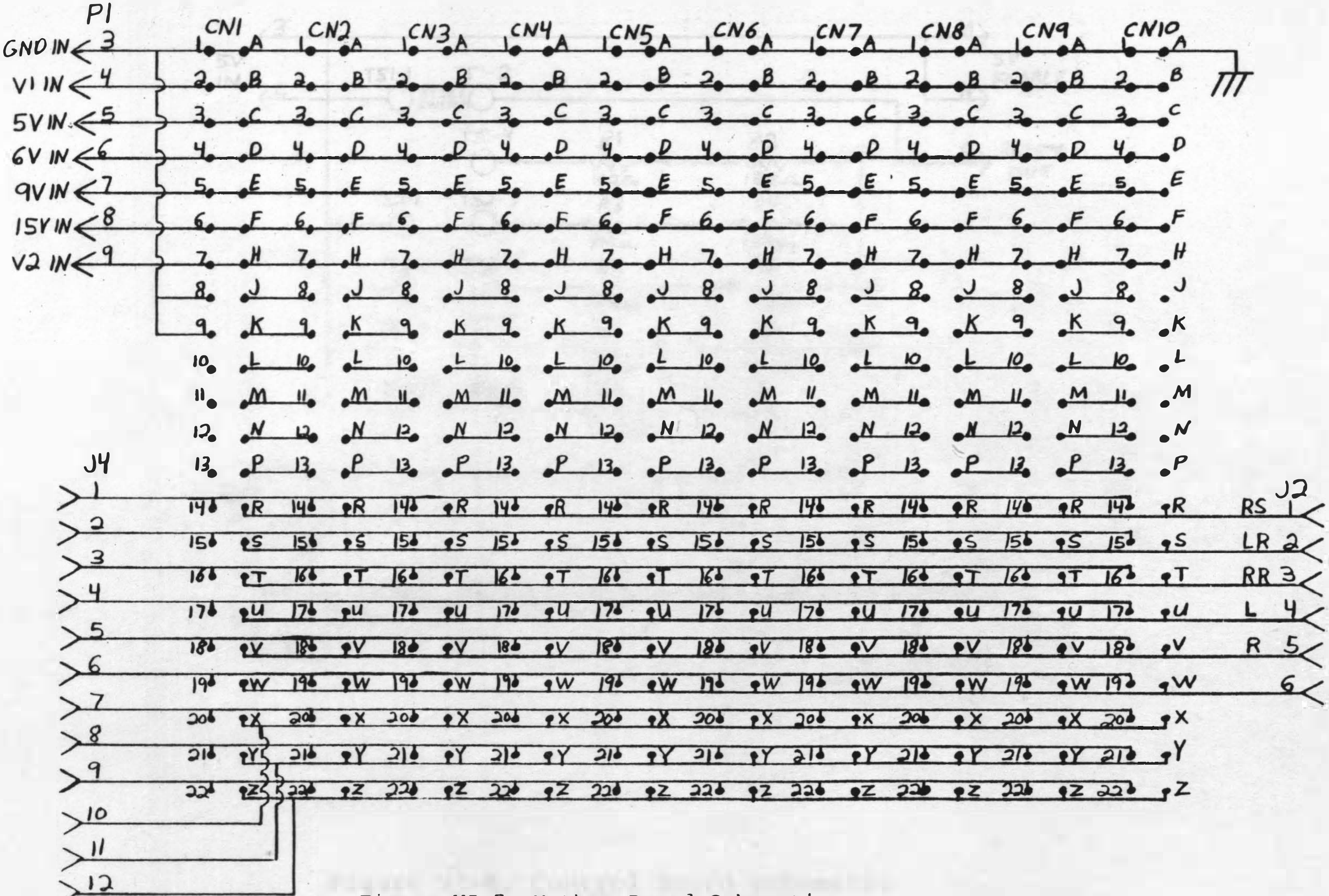

Figure VI-7. Mother Board Schematic

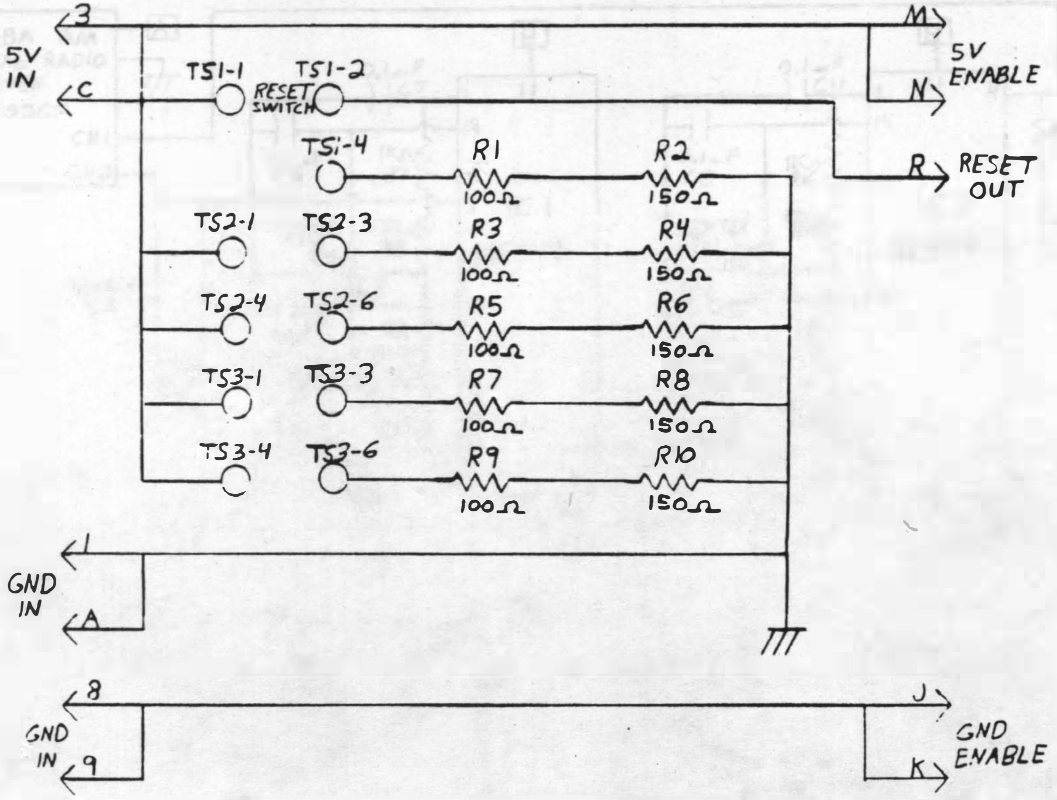

Figure VI-8. Control Board Schematic

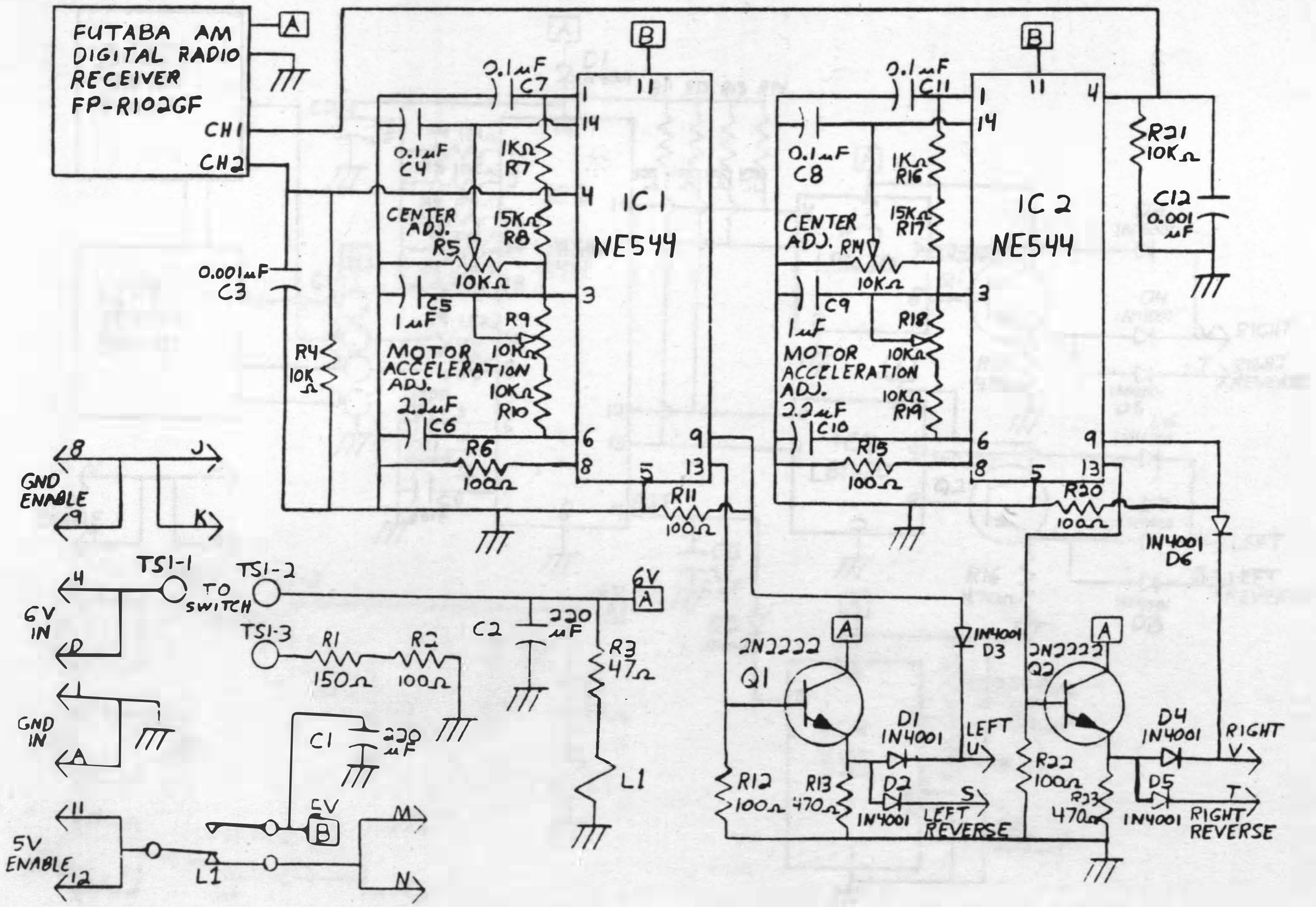

Figure VI-9. Radio Control Board Schematic

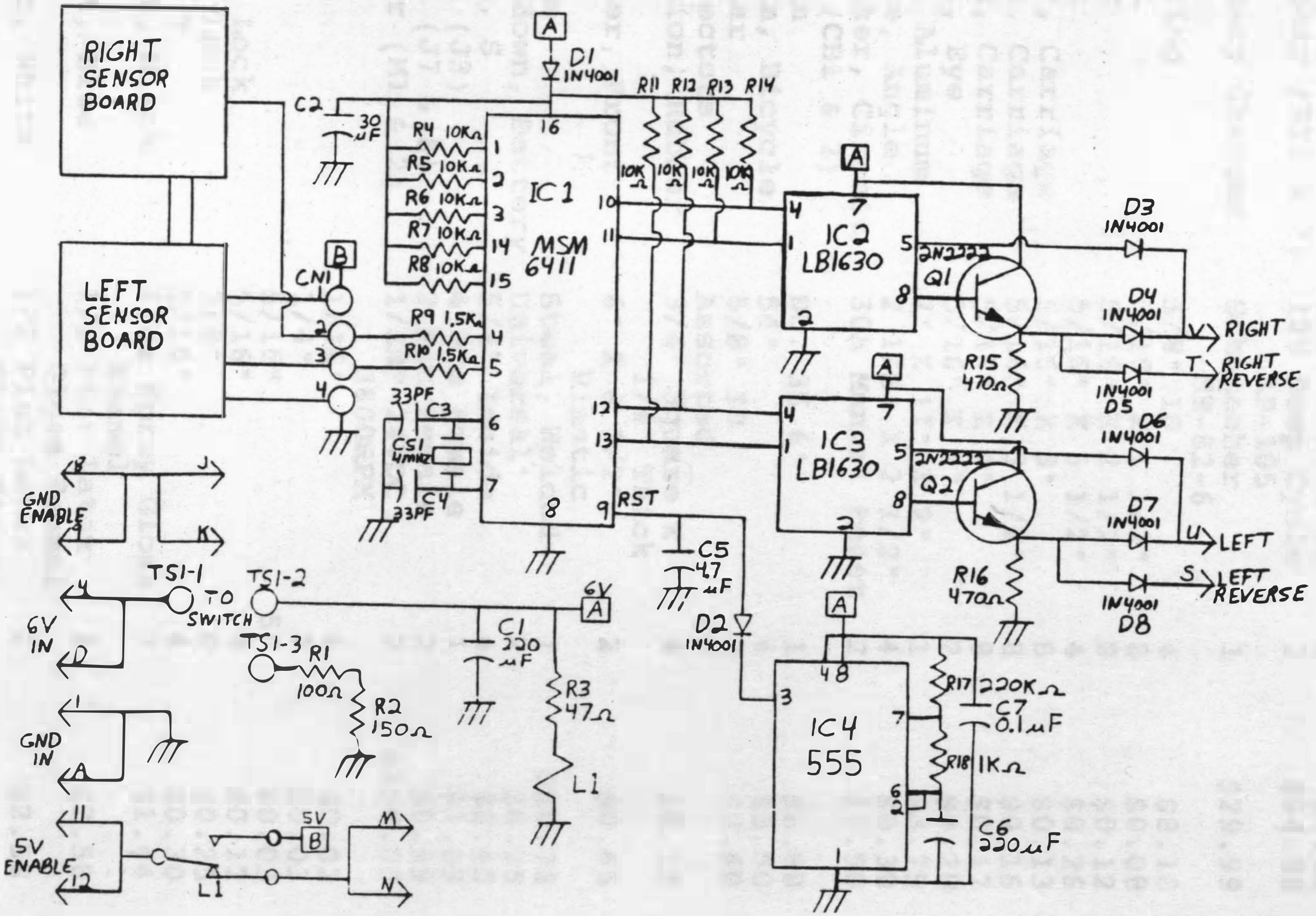

Figure VI-10. Ultrasonic Control Board Schematic

PARTS LIST: CHASSIS

ITEM	TYPE	QUAN.	COST EACH	NET COST
Bar, Metal	1/8" X 1" X 13"	1	$0.41	$0.41
Battery (BT1 & 2)	12V Deep Cycle AP-105	2	$64.88	$129.76
Battery Charger	Schumacher SE-82-6	1	$29.99	$29.99
Bearing	5/8" ID	4	$8.10	$32.40
Bolt	5/16" X 1 1/2"	8	$0.08	$0.64
Bolt	5/16" X 2 1/2"	2	$0.12	$0.24
Bolt	5/16" X 5 1/2"	4	$0.26	$1.04
Bolt, Carriage	5/16" X 3"	8	$0.13	$1.04
Bolt, Carriage	5/16" X 3 1/2"	8	$0.16	$1.28
Bolt, Carriage	5/16" X 4"	8	$0.17	$1.36
Bolt, Eye	5/16" X 6"	2	$0.28	$0.56
Box, Aluminum	7" X 11" X 2"	1	$3.79	$3.79
Brace, Angle	2 1/2" X 2 1/2"	4	$0.30	$1.20
Breaker, Circuit (CB1 & 2)	30A Manual Reset	2	$7.50	$15.00
Chain	No. 35 6′	1	$8.88	$8.88
Chain, Bicycle	54"	4	$3.50	$14.00
Collar	5/8" ID	2	$0.60	$1.20
Connectors	Assorted	60		$10.00
Cushion, Rubber	3/4" Square X 1/4" Thick	4	$0.19	$0.76
Fender, Front	6" X 8 1/2" Plastic	2	$0.65	$1.30
Frame	Steel, Welded	1	$60.78	$60.78
Holddown, Battery	Universal	2	$6.35	$12.70
Hook, S	5/8" Inside	4	$0.40	$1.60
Jack (J3)	4 Pin Female	1	$1.09	$1.09
Jack (J7 & 8)	2 Pin Female	2	$0.99	$1.98
Motor (M1 & 2)	1/3HP 24VDC 3800RPM	2	$150.00	$300.00
Nut	1/16"	4	$0.02	$0.08
Nut	1/4"	8	$0.03	$0.24
Nut	5/16"	50	$0.03	$1.50
Nut, Lock	5/16"	8	$0.12	$0.96
Nut, Lock	5/8"	6	$0.25	$1.50
Nut, T	5/16"	4	$0.30	$1.20
Paint, Black	12oz Spray Gloss Enamel	3	$1.44	$4.32
Paint, Blue	1/2 Pint Latex Gloss Enamel	1	$2.58	$2.58
Paint, White	1/2 Pint Latex Gloss Enamel	1	$2.58	$2.58
Pipe, Plastic	7/8" OD 5′ Long	1	$2.45	$2.45
Pipe, Steel	1/2" OD 4.5′	1	$1.80	$1.80
Pipe, Steel	3/4" OD 8"	1	$6.00	$6.00

PARTS LIST: CHASSIS CONTINUED

Plate, Data	3/4" X 2" Brass	1	$4.00	$4.00
Plug (P6 & 8)	2 Pin Male	2	$0.99	$1.98
Reducer, Speed	10:1 Right Angle	2	$228.00	$456.00
Relay (L1 & 2)	SPST 24VDC 150A	2	$14.08	$28.16
Relay (L3 & 5)	DPST 12VDC 150A	2	$30.00	$60.00
Relay (L4 & 6)	DPST 12VDC 150A GNDed Coil	2	$20.00	$40.00
Rod	5/8" X 3'	3	$4.25	$12.75
Rod, Threaded	5/16" X 3'	2	$1.75	$3.50
Screw	1/16" X 1/2"	4	$0.02	$0.08
Screw	1/4" X 1"	8	$0.06	$0.48
Screw, Wood	1 1/2"	60	$0.03	$1.80
Screw, Wood	1" with 1/2" Hex Head	8	$0.08	$0.64
Screw, Wood	1 1/2" with 1/2" Hex Head	6	$0.08	$0.48
Spring, Conical	1" Long	4	$0.45	$1.80
Sprocket	10 Tooth	2	$4.99	$9.98
Sprocket	44 Tooth Bicycle	8	$5.00	$40.00
Sprocket	84 Tooth No. 35	2	$11.43	$22.86
Standoff, PCB	1/2"	8	$0.30	$2.40
Strap	1" X 4' with Buckle	1	$4.29	$4.29
Strip, Metal	1/2" X 25"	1	$0.50	$0.50
Strip, Terminal (TS1)	5 Position	1	$1.89	$1.89
Strip, Terminal (TS2)	6 Position	1	$1.59	$1.59
Switch, Bumper (S1-4)	Push-button N/C SPST Mnt.	4	$0.45	$1.80
Washer, Flat	1/4"	4	$0.02	$0.08
Washer, Flat	5/16"	31	$0.02	$0.62
Washer, Lock	1/16"	4	$0.01	$0.04
Washer, Lock	1/4"	8	$0.01	$0.08
Washer, Lock	5/16"	38	$0.02	$0.76
Wheel and Tire Assembly	4.10/3.50 X 6"	6	$22.00	$132.00
Wire	Assorted			$10.00
Wood, Pine	1" X 8" X 10'	1	$3.15	$3.15
Wood, Pine	1" X 12" X 6'	1	$4.62	$4.62
Wood	2" X 4" X 12'	1	$1.29	$1.29

CHASSIS TOTAL $1507.83

PARTS LIST: POWER SUPPLY

ITEM	TYPE	QUAN.	COST EACH	NET COST
Board, Circuit	3 3/8" X 2 7/8"	1	$2.29	$2.29
Jack (J1)	9 Pin Female	1	$1.59	$1.59
Capacitor (C1 & 4)	0.1 microfarad	2	$0.15	$0.30
Capacitor (C2, 3, 5, 6)	1 microfarad	4	$0.19	$0.76
Int. Circuit (IC1)	5V Regulator 7805	1	$0.49	$0.49
Int. Circuit (IC2, 3, 5, 6)	Adj. Regulator 317T	4	$0.69	$2.76
Int. Circuit (IC4)	15V Regulator 7815	1	$0.49	$0.49
Resistor (R1)	680 ohm 1/2W	1	$0.10	$0.10
Resistor (R2, 7, 10, 13)	22 ohm 1/2W	4	$0.10	$0.40
Resistor (R3)	150 ohm 1/2W	1	$0.10	$0.10
Resistor (R4, 8, 11, 14)	220 ohm 1/2W	4	$0.10	$0.40
Resistor (R5)	82 ohm 1/2W	1	$0.10	$0.10
Resistor (R6)	1500 ohm 1/2W	1	$0.10	$0.10
Resistor (R9, 12)	5K ohm variable	2	$0.37	$0.74
			POWER SUPPLY TOTAL	$10.62

PARTS LIST: MOTHER BOARD

ITEM	TYPE	QUAN.	COST EACH	NET COST
Board, Circuit	6" X 8"	1	$2.99	$2.99
Connector (CN1 - CN10)	44 Contact Card Edge	10	$2.25	$22.50
Jack (J2)	6 Pin Female	1	$1.39	$1.39
Jack (J4)	12 Pin Female	1	$1.69	$1.69
Nut	1/16"	20	$0.02	$0.40
Plug (P1)	9 Pin Male	1	$1.59	$1.59
Screw	1/16" X 1/2"	20	$0.02	$0.40
Wire	Assorted			$2.00
			MOTHER BOARD TOTAL	$32.96

PARTS LIST: MOTOR DRIVE BOARD

ITEM	TYPE	QUAN.	COST EACH	NET COST
Board, Circuit	3 3/8" X 2 7/8"	1	$2.29	$2.29
Capacitor (C1)	0.1 microfarad	1	$0.15	$0.15
Capacitor (C2)	500 microfarad	1	$0.29	$0.29
Diode (D1 - 6)	1N4001	6	$0.08	$0.48
Int. Circuit (IC1)	5V Regulator 7805	1	$0.49	$0.49
Plug (P2)	6 Pin Male	1	$1.39	$1.39
Transistor (Q1, 3, 5, 7, 9)	2N2222 NPN	5	$0.13	$0.65
Transistor (Q2, 4, 6, 8)	TIP42 PNP	4	$0.59	$2.36
Relay	SPDT 12V 10A	1	$2.99	$2.99
Resistor (R1, 3, 4, 6, 7, 9, 10, 12)	220 ohm 1/4W	8	$0.08	$0.64
Resistor (R2, 5, 8, 11)	470 ohm 1/2W	4	$0.10	$0.40
Resistor (R13)	22K ohm 1/4W	1	$0.08	$0.08
Resistor (R14, 15, 18)	4700 ohm 1/4W	3	$0.08	$0.24
Resistor (R16)	150 ohm 1/4W	1	$0.08	$0.08
Resistor (R17)	330 ohm 1/2W	1	$0.10	$0.10
Strip, Terminal (TS1, 3, 4)	2 Position Mini	3	$0.50	$1.50
			MOTOR DRIVE BOARD TOTAL	$14.13

PARTS LIST: EMERGENCY LIGHT BOARD

ITEM	TYPE	QUAN.	COST EACH	NET COST
Board, Circuit	3 3/8" X 2 7/8"	1	$2.29	$2.29
Relay (L1)	SPDT 9V 2A	1	$2.99	$2.99
Resistor (R5)	56K ohm 1/2W	1	$0.10	$0.10
Resistor (R6)	22K ohm 1/2W	1	$0.10	$0.10
Resistor (R7)	Photocell CL703	1	$0.40	$0.40
Resistor (R8)	25K ohm variable	1	$0.61	$0.61
Resistor (R9)	150 ohm 1/2W	1	$0.10	$0.10
Transistor (Q1)	2N2222 NPN	1	$0.13	$0.13
			EMERGENCY LIGHT BOARD TOTAL	$6.72

PARTS LIST: HEAD

ITEM	TYPE	QUAN.	COST EACH	NET COST
Container	Plastic	1	$6.00	$6.00
Box, Aluminum	7" X 11" X 2"	1	$3.79	$3.79
Diode, Red (D1 - 6)	Light Emitting	6	$1.79	$10.74
Diode, Red (D7 - 8)	Light Emitting	2	$1.00	$2.00
Fuse (F1)	AGC-3A	1	$0.35	$0.35
Fuse (F2)	AGC-2A	1	$0.35	$0.35
Fuse (F3)	AGC-5A	1	$0.35	$0.35
Grommet	1/2" ID Rubber	1	$0.05	$0.05
Light (B1)	12V Clear	1	$3.23	$3.23
Nut	1/16"	23	$0.02	$0.46
Nut	1/8"	4	$0.02	$0.08
Nut, T	1/4"	4	$0.30	$1.20
Outlet, Accessory	12V	1	$8.65	$8.65
Plug (P3)	4 Pin Male	1	$1.09	$1.09
Resistor (R1)	220 ohm 1W	1	$0.20	$0.20
Resistor (R2)	220 ohm 1/2W	1	$0.10	$0.10
Resistor (R3)	100 ohm 1/2W	1	$0.10	$0.10
Resistor (R4)	680 ohm 1/2W	1	$0.10	$0.10
Screw	1/16" X 1"	19	$0.02	$0.38
Screw	1/16" X 1 1/2"	4	$0.02	$0.08
Screw	1/8" X 1"	4	$0.04	$0.16
Screw	1/4" X 1"	4	$0.06	$0.24
Spacer	1/8" X 1/2"	6	$0.05	$0.30
Standoff, PCB	1/2"	8	$0.30	$2.40
Switch, Red (S1)	Lighted Rocker N/O SPST	1	$2.17	$2.17
Switch, Blue (S2)	Lighted Rocker N/O SPST	1	$2.17	$2.17
Switch (S3, 4, 5, 7, 8)	Push-button N/O SPST	5	$1.69	$8.45
Switch (S6)	Push-button N/O SPST Mnt.	1	$1.59	$1.59
Switch (S9)	SPDT Center Off	1	$3.79	$3.79
Washer, Flat	1/16"	11	$0.01	$0.11
Washer, Flat	1/8"	4	$0.02	$0.08
Washer, Lock	1/16"	8	$0.01	$0.08
Washer, Lock	1/8"	4	$0.02	$0.08
Wire	Assorted			$2.00
			HEAD TOTAL	$62.92

PARTS LIST: CONTROL BOARD

ITEM	TYPE	QUAN.	COST EACH	NET COST
Board, Circuit	44 Connector 4" X 4 1/2"	1	$3.49	$3.49
Resistor (R1, 3, 5, 7, 9)	100 ohm 1/4W	5	$0.08	$0.40
Resistor (R2, 4, 6, 8, 10)	150 ohm 1/4W	5	$0.08	$0.40
Strip, Terminal (TS1)	4 Position Mini	1	$1.00	$1.00
Strip, Terminal (TS2 - 3)	6 Position Mini	2	$1.50	$3.00
			CONTROL BOARD TOTAL	$8.29

PARTS LIST: ULTRASONIC SENSOR BOARDS

ITEM	TYPE	QUAN.	COST EACH	NET COST
Board, Circuit	1 3/4" X 1 3/4"	2	$0.70	$1.40
Capacitor (C1, 2, 6, 7)	470 picofarad	4	$0.10	$0.40
Capacitor (C3, 8)	0.01 microfarad	2	$0.10	$0.20
Capacitor (C4, 9)	100 microfarad	2	$0.19	$0.38
Capacitor (C5, 10)	0.001 microfarad	2	$0.10	$0.20
Capacitor (C26, 27)	2 picofarad	2	$0.32	$0.64
Diode (D1, 2)	1S1588	2	$0.08	$0.16
Resistor (R1, 7, 9, 10, 16, 18)	100K ohm 1/4W	6	$0.08	$0.48
Resistor (R2, 4, 11, 13)	1M ohm 1/4W	4	$0.08	$0.32
Resistor (R3, 5 12, 14)	12K ohm 1/4W	4	$0.08	$0.32
Resistor (R6, 15)	10K ohm 1/4W	2	$0.08	$0.16
Resistor (R8, 17)	1000 ohm 1/4W	2	$0.08	$0.16
Resistor (VR1, 2)	10K ohm 1/4W	2	$0.61	$1.22
Transducer, Ultrasonic	T41.7-16	2	$5.99	$11.98
Transistor (Q1, 2, 3, 4, 5, 6)	2SC945 NPN	6	$0.13	$0.78
			ULTRASONIC SENSOR BOARDS TOTAL	$18.80

PARTS LIST: RADIO CONTROL BOARD

ITEM	TYPE	QUAN.	COST EACH	NET COST
Board, Circuit	44 Connector 4" X 4 1/2"	1	$3.49	$3.49
Capacitor (C1, 2)	220 microfarad	2	$0.19	$0.38
Capacitor (C3, 12)	0.001 microfarad	2	$0.10	$0.20
Capacitor (C4, 7, 8, 11)	0.1 microfarad	4	$0.15	$0.60
Capacitor (C5, 9)	1 microfarad	2	$0.12	$0.24
Capacitor (C6, 10)	2.2 microfarad	2	$0.25	$0.50
Diode (D1 - 6)	1N4001	6	$0.08	$0.48
Int. Circuit (IC1, 2)	Servo Amp. NE544	2	$1.75	$3.50
Relay (L1)	SPDT 5V 2A	1	$2.39	$2.39
Resistor (R1)	150 ohm 1/4W	1	$0.08	$0.08
Resistor (R2, 6, 11, 12, 15, 20, 22)	100 ohm 1/4W	7	$0.08	$0.56
Resistor (R3)	47 ohm 1/4W	1	$0.08	$0.08
Resistor (R4, 10, 19, 21)	10K ohm 1/4W	4	$0.08	$0.32
Resistor (R5, 9, 14, 18)	10K ohm variable	4	$0.61	$2.44
Resistor (R7, 16)	1000 ohm 1/4W	2	$0.08	$0.16
Resistor (R8, 17)	15K ohm 1/4W	2	$0.08	$0.16
Resistor (R13, 23)	470 ohm 1/4W	2	$0.08	$0.16
Socket, IC	14 Pin	2	$0.12	$0.24
Strip, Terminal (TS1)	4 Position Mini	1	$1.00	$1.00
Transistor (Q1, 2)	2N2222 NPN	2	$0.13	$0.26

RADIO CONTROL BOARD TOTAL	$17.24
+ HOBBY RADIO (2 CHANNEL)	$64.95
TOTAL	$82.19

PARTS LIST: ULTRASONIC CONTROL BOARD

ITEM	TYPE	QUAN.	COST EACH	NET COST
Board, Circuit	44 Connector 4" X 4 1/2"	1	$3.49	$3.49
Capacitor (C1, 6)	220 microfarad	2	$0.19	$0.38
Capacitor (C2)	30 microfarad	1	$0.15	$0.15
Capacitor (C3, 4)	33 picofarad	2	$0.10	$0.20
Capacitor (C5)	4.7 microfarad	1	$0.12	$0.12
Capacitor (C7)	0.1 microfarad	1	$0.15	$0.15
Connector (CN1)	4 Pin	1	$1.65	$1.65
Crystal (CS1)	4 MHZ	1	$1.19	$1.19
Diode (D1 - 8)	1N4001	8	$0.08	$0.64
Int. Circuit (IC1)	Microprocessor MSM6411	1	$8.95	$8.95
Int. Circuit (IC2, 3)	Motor Drive LB1630	2	$1.75	$3.50
Int. Circuit (IC4)	Timer NE555	1	$0.35	$0.35
Relay (L1)	SPDT 5V 2A	1	$2.39	$2.39
Resistor (R1)	100 ohm 1/4W	1	$0.08	$0.08
Resistor (R2)	150 ohm 1/4W	1	$0.08	$0.08
Resistor (R3)	47 ohm 1/4W	1	$0.08	$0.08
Resistor (R4 - 8, 11-14)	10K ohm 1/4W	9	$0.08	$0.72
Resistor (R9, 10)	1500 ohm 1/4W	2	$0.08	$0.16
Resistor (R15, 16)	470 ohm 1/4W	2	$0.08	$0.16
Resistor (R17)	220K ohm 1/4W	1	$0.08	$0.08
Resistor (R18)	1000 ohm 1/4W	1	$0.08	$0.08
Socket, IC	8 Pin	3	$0.11	$0.33
Socket, IC	16 Pin	1	$0.13	$0.13
Strip, Terminal (TS1)	4 Position Mini	1	$1.00	$1.00
Transistor (Q1, 2)	2N2222 NPN	2	$0.13	$0.26
			ULTRASONIC CONTROL BOARD TOTAL	$26.32

PARTS LIST: ULTRASONIC TRANSMITTER

ITEM	TYPE	QUAN.	COST EACH	NET COST
Board, Circuit	1 3/4" X 3 5/8"	1	$1.39	$1.39
Battery	9V	1	$0.59	$0.59
Case, Transmitter	3 7/16" X 2 5/16 X 1 3/16"	1	$3.60	$3.60
Capacitor (C1, 2)	33 picofarad	2	$0.10	$0.20
Capacitor (C3)	3.3 microfarad	1	$0.10	$0.10
Capacitor (C4)	10 microfarad	1	$0.13	$0.13
Capacitor (C5)	0.01 microfarad	1	$0.10	$0.10
Capacitor (C6)	0.1 microfarad	1	$0.15	$0.15
Connector, Battery	9V, 2 Wire	1	$0.20	$0.20
Crystal (CS1)	4 MHZ	1	$1.19	$1.19
Diode (D1)	1S1588	1	$0.08	$0.08
Diode (ZD1)	RD6.2E 6.2V	1	$0.15	$0.15
Int. Circuit (IC1)	Microprocessor BU3204	1	$4.95	$4.95
Int. Circuit (IC2)	Hex Inverter BU4069	1	$0.25	$0.25
Resistor (R1)	390 ohm 1/4W	1	$0.08	$0.08
Resistor (R2)	1M ohm 1/4W	1	$0.08	$0.08
Resistor (R3)	100K ohm 1/4W	1	$0.08	$0.08
Resistor (R4)	120K ohm 1/4W	1	$0.08	$0.08
Resistor (R5, 8)	10K ohm 1/4W	2	$0.08	$0.16
Resistor (R6)	2M ohm 1/4W	1	$0.08	$0.08
Resistor (R7)	1000 ohm 1/4W	1	$0.08	$0.08
Switch (T3, 4)	Slide SPST	2	$0.40	$0.80
Switch	Push-button N/O SPST Mnt.	4	$1.20	$4.80
Transducer, Ultrasonic	T41.7-16	1	$5.99	$5.99

ULTRASONIC TRANSMITTER TOTAL $25.31

TOTAL COST FOR COMPLETE PROTOTYPE $1796.09

IV. OPERATIONAL TEST OF SCMPR

A. Operation of the Controls

One design goal for SCMPR was to simplify all controls. Because the prototype is a test model, additional switches were added to disable different sections for safety reasons. These additional switches can be eliminated in a production model.

To turn on SCMPR, turn on the following switches in this order:

1. Power Supply Switch S2.
2. Motor Drive Switch S1.
3. Either the Ultrasonic or Radio Control transmitter.
4. Either the Ultrasonic Enable, S3, or the Radio Control Enable, S4, that corresponds to the correct transmitter.
5. Circuit Breakers CB1 and CB2.

To turn off SCMPR, turn off the switches in the reverse order.

To operate SCMPR in the Ultrasonic Mode, simply point the transmitter in the general direction of SCMPR and push the button with the arrow for the direction SCMPR is to go: right, left, forward, or reverse. If the operator wants SCMPR to follow, he/she simply turns on the switch marked "FOLLOW" and clips the transmitter to his/her belt with the transmit end pointing to the rear. SCMPR will stop if the Follow Switch is off and no direction switches are being pressed. The direction switches will override the Follow Mode if they are pressed when the Follow Switch is on.

To operate SCMPR in the Radio Control Mode, the left lever on the transmitter is used to control SCMPR's left motor and the right lever to control the right motor. Moving both levers up or down will cause SCMPR to go forward or backward. Move one lever up or down to drive one motor and make a slow turn. Move the levers in opposite directions to cause SCMPR to spin around without changing location. If neither lever is held, they will both return to center and SCMPR will stop.

For operation at night or in areas with limited illumination, SCMPR is equipped with an emergency light. To enable this light, press Emergency Light Switch S5. When this switch is on, the light will turn on whenever the photoresistor in the side of the head detects a sufficiently low level of illumination and will turn off when the illumination returns to normal. This light radiates in all directions and provides light to see by and to alert others that the robot is in the area.

For safety, SCMPR is equipped with bumpers which have switches to cut off the motor drive if either bumper makes contact with an obstacle. Once either bumper stops the motors, they cannot start again until the Reset Switch S6 is pressed or until the Motor Drive Board is turned off and back on. The reset must be done manually in order to force the operator to investigate the cause of the accident to ensure no one was hurt and nothing was damaged.

Switches S7 and S8 are unused and are connected to the Control Board. The Control Board provides a circuit so that the indicators will light if the switches are on. This allows the switches to be tested and provides a connection for the unused wires.

Switch S9 has no connections, but has been provided for the addition of a memory. It is off in the center and has two on positions. This allows one position to activate the memory to record SCMPR's actions and the other position to cause SCMPR to repeat the actions recorded.

SCMPR has a 12V outlet in the side of the head. This outlet accepts standard adapters made to plug into automobile cigarette lighters and allows the use of numerous devices designed for cars.

B. <u>Tests</u>

SCMPR was tested outdoors on snow, ice, and pavement. The first test was run using radio control. SCMPR responded well and could be controlled from a distance of 100 meters SCMPR was not tested from further away because of safety concerns, but the radio used has a limit of approximately one mile. On ice, SCMPR slid in turns in spite of its six wheel drive. SCMPR's speed was comparable to a slow walk. Touching either bumper stopped SCMPR and it did not start again until reset. When the drives were stopped, SCMPR came to a halt within two to three feet in spite of the lack of brakes.

With the ultrasonics, SCMPR was limited to a range of approximately 10 to 15 feet. SCMPR could not detect the ultrasonic signal from the rear. This presented a slight problem when turning SCMPR around. It would turn until the angle became too great and it lost the signal. After moving the transmitter around to the front, SCMPR would again respond to the control. In the Follow Mode, SCMPR turned using only one drive. This worked well on pavement and light snow, but on ice it caused a wide turn radius, as much as 10 feet.

The emergency light was tested by enabling it and leaving it until the evening light was dim enough to turn it on. It was also tested in a dark room by turning the lights on and off and observing the emergency light's response. The emergency light responded properly during all tests.

The outlet was tested with a meter and a spotlight made to plug into a car. Power was present in both cases.

A load test showed that SCMPR could carry 200 pounds, but this caused it to slow down in turns on dry pavement.

Endurance varied widely with the load carried, the number of turns made, and the amount of time the motors ran. SCMPR draws 22 to 24 amps when running continuously in a straight line. The batteries were designed to supply this amount of current for about 3 hours. This is the maximum running time for continuous use. SCMPR's electronics draw less than 2 amps when idle. For applications where SCMPR sits and waits while being loaded or unloaded, the endurance can be extended considerably. (The batteries are rated by the manufacturer to supply 5 amps for over 21 hours.)

Earlier tests were made using power transistors to control the motors and give SCMPR a speed control. The drive was successful for straight line operation, but the transistors didn't allow the motors to draw an initial current surge large enough to turn with a skid steer.

A higher gear ratio was tested that provided a maximum speed of about 4 1/2 miles per hour, a military speed march rate, but the motors drew over 30 amps each when turning with the skid steer. With a front-wheel steering system, the transistor drive control and the higher gear ratio would both be practical.

A speech recognition voice circuit that is speaker independent was tested using a Motorola VCP200 chip, but its effective range was only one foot. If the sound pickup can be redesigned to be more sensitive without adding background noise, a voice circuit may be practical. The current range makes voice control dangerous for this size of robot.

C. Recommended Maintenance

In order to keep SCMPR performing properly, some preventive maintenance will be necessary. Checks that need to be performed before operation are:

1. Battery water level and charge.
2. Tire pressure (35 pounds).
3. Chain tension (Adjust until tight enough to allow only 1 inch movement up and down between sprockets using finger pressure for all 6 chains.).
4. Check the seating of the cards plugged into the Mother Board.
5. Test all functions.

SCMPR's construction is simple enough to allow it to be maintained by the operator with the exception of the electronics. Any qualified electronics technician should have no difficulty repairing the simple circuits used with the schematics and parts lists provided. However, a production model should include a service manual to make repairs easier.

D. Summary

As a result of the tests performed, two conclusions were reached: (1) SCMPR is a practical robot and can perform the functions it was designed for and (2) some modifications should be made to the design to make it easier to use and to enhance its capabilities. Recommended changes are discussed below.

A charge meter for the batteries would free the operator from the worry of losing power at an inopportune moment. Also, a built-in 24V battery charger and maintenance free batteries would save considerable bother and time when recharging the batteries.

Presently, if SCMPR should break down, it is necessary to disconnect the chains from the motors to allow it to be rolled. It is too heavy to carry or be moved easily otherwise. The wheels should be changed to a type that can be disengaged from the sprockets with a release lever similar to those used on some riding lawn mowers.

SCMPR should have a speed control and faster top speed in order to follow a person at whatever speed he chooses to walk. In order to accomplish this, the skid steer should be eliminated (at least from some models) so that a transistor speed control and a higher gear ratio can be used. This will also increase the maximum running time per battery charge.

After rough use, the cards plugged into the Mother Board can come loose. They should be replaced with a type that have connectors with screws to hold them in place to eliminate that problem.

The box on SCMPR was made of wood and the head was converted from a trashcan. This is not appropriate for a production model. Both should be replaced with either standardized plastic or metal containers.

The last change recommended is the addition of an obstacle detector. A simple ultrasonic device can be added that would enable the robot to detect and avoid obstacles or to determine how close it is following behind someone and adjust its speed accordingly.

V. PRODUCTION COST ESTIMATE

A. Introduction

The cost of mass producing a robot will depend largely upon how many are produced. That number, in turn, will be determined by the size of the market. Since the size of the market is difficult to determine, especially for a product not already being sold by anyone else, the cost of producing a minimum number with full-time employees at a price that would allow a company to break even will be examined.

To increase its odds for success, the company will need to employ at least two people. One person needs to be technically qualified to assemble the robot and the other to handle administration and sales. The maximum number of robots produced per year will depend upon how many hours it takes to assemble each one and how many hours per year one employee will be able to work. The number of hours required to assemble a robot is presented below and is based upon experience obtained from the construction of the prototype.

TASK	TIME REQUIRED
1. Drill holes in frame, head, and sprockets.	1 hour
2. Cut metal and plastic parts.	1 hour
3. Paint frame.	1/2 hour
4. Assemble electronics.	1 hour
5. Assemble chassis, box, and head.	3 1/2 hours
6. Paint box.	1/2 hour
7. Final assembly and test.	1/2 hour
TOTAL	8 hours

The total number of hours available to work each year (assuming no overtime and considering weekends, holidays, and vacations) will be: 8 hours/day X 5 days/week X 50 weeks/year = 2000 hours/year. Divide the 2000 hours/year by the 8 hours it takes to produce each robot and the results are 250 robots per year for one employee. Therefore, all the estimates given will be for the production of 250 robots per year.

Now that the number of employees to be used and the annual number of robots to be produced have been determined, the cost per robot must be computed. This cost will be based on the total annual expenses of the company divided by the total annual production of robots. To compute the annual expenses of the company, the cost of the building, utilities, parts, labor, equipment, insurance, advertising, shipping, and taxes will all be considered.

B. The Building and Utilities

The type and size of building used can vary. The most important factors to consider when choosing a building are the cost and the size. The cost, in terms of payments or rent, will vary with the size. The exact size will depend upon how much storage space is desired. The amount of storage space desired will depend upon how fast the product can be sold after it is completed. Since a new company can only make a rough estimate of sales, the amount of storage space desired is subjective. Therefore, in order to determine the cost of a building for this paper, the size of buildings that are typically available in this area (mideastern South Dakota) will be examined.

Metal sided buildings of about 2500 square feet are available for approximately $20,000 used to $60,000 new. Monthly payments are usually about 1.1% of the total price ($220 for a used building to $660 for a new one). Utilities for an older building of this type recently averaged another $220 per month for an automotive repair garage. Telephone service can add an additional $100. Assuming the company bought an older building, it would be paying $540 per month. Since capital will most likely be limited when starting a new company, no further consideration will be given to the use of a new building.

One cost not shown above is the initial down payment most lending institutions require. Because this payment will usually be one third the total cost, a new company may want to consider renting in order to save its capital. Renting may be more expensive, but it does offer some advantages. Besides eliminating the need for a large amount of capital, renting does away with the need for insurance on the building. Renting also allows the business to relocate without tieing up a large part of its capital buying a new building while trying to sell its old one.

An area of 500 square feet is sufficient to allow SCMPR to be assembled without crowding assembly and fabrication stations together. Administrative offices can be housed in an area of 200 square feet. This leaves 1800 square feet left for storage. Each finished robot requires 10 square feet for storage. The parts for one will take approximately the same area. This leaves enough room to store 90 robots and the parts for 90 more. This is more than enough room for the first year and it allows room for expansion the following years.

C. Parts

The cost of manufacturing a production model of SCMPR will be close to the cost of manufacturing the prototype. The cost of the prototype was listed earlier as $1796.09. This price was based on the retail cost of parts and excluded labor. A manufacturing company will be able to buy parts below retail and will be able to take advantage of price breaks offered by suppliers for large quantities.

The formula for the economic order quantity gives the most economical size order that a company should place. The formula assumes that the company will have sufficient capital to take advantage of this order size. A new company often will not have the capital to take advantage of this formula. Because of this and because of the large number of parts involved, we will base our order quantities on the monthly demand for parts.

To build 250 robots per year, a company will produce about 21 per month. A break down of the more expensive parts is listed below along with the price savings obtained per robot by purchasing the quantity required for 21 robots at the rate paid by a manufacturing company.

SUPPLIER	PART	QUANTITY	PRICE EACH	SAVINGS PER ROBOT
Dayton	Speed Reducer	42	$161.00	$134.00
Dayton	Motor	42	$117.18	$65.64
Goodyear	Battery	42	$42.00	$45.76
Montieth Welding	Frame	21	$52.00	$8.78
Swisher	Wheel Tire	126	$15.90	$36.60
			TOTAL SAVINGS	$290.78

These five parts represent $1078.54 of the $1796.09 in parts for the prototype SCMPR. $290.78 represents a savings of 27% average for the parts listed. Similar savings can be obtained on the remaining parts. Instead of presenting the complete parts breakdown showing this, 27% will be used as the percentage of savings on the complete robot. 27% of $1796.09 is an overall savings of $485, leaving a total cost for parts of $1311. This cost will include shipping.

D. Labor

Earlier, it was assumed two employees would be working for the company. One of these two employees will be working full time assembling the robots while the other will spend half of his/her time working in administration and the other half advertising and promoting the business. Therefore, half of one employee's salary could be considered as an advertising expense. For simplicity, his/her salary will be computed as labor.

Qualified technicians who could assemble SCMPR are usually paid around $25,000 per year. If that number is used for the salaries of both employees, the annual labor cost is $50,000 per year. An additional 7.5% will be added for FICA taxes, bringing the annual total to $53,750. If no benefits are payed and no overtime allowed, this is the final cost.

E. Equipment

If the frame for SCMPR continues to be made by another firm, the only equipment necessary to assemble SCMPR is the proper tools and a drill press. An appropriate tool set with wrenches, screwdrivers, and soldering tools can be purchased for under $200. A drill press can be purchased used for about $200 or new for about $600. Since building large numbers is not planned at this stage, a used drill press will do. Later, as the business expands, an arc-welder, a milling machine, and a power hacksaw can be added to build the frames in the factory. A press break and a shear will allow aluminum and sheet steel to be formed into new or alternative parts. All of these additional machines represent a substantial investment in thousands of dollars each except for the welder and the power hacksaw, which can be purchased for under a thousand dollars each when new. Do to these expenses, it is preferable to have the metalwork done elsewhere until the company grows.

F. Insurance

Certain types of insurance are recommended for a light manufacturing company. Fire insurance to protect against fire damage, casualty and liability insurance to provide protection in case of injuries occurring on company property or those caused by the product, property insurance to protect against the loss of or damage to company equipment or property, and Workman's Compensation, required by law if the company has employees.

Exact insurance costs cannot be obtained until the company has purchased its equipment and set up for operation. However, the following estimates, based on discussions with an insurance agent, should be close to the rates paid in this area. Fire insurance will cost about $1500 per year for the company discussed so far. Casualty insurance will be high because of the unusual nature of the product, an estimate is about $3000 per year. Property insurance will be much less, about $500 per year. Workman's Compensation can be completely avoided if the company is organized as a partnership and hires no additional employees.

The total bill for the insurance discussed is $5000 per year.

G. Advertising

Many means of advertising are available and their costs vary widely with their effectiveness. A major newspaper will cost an average of $15.00 for a 2 inch by 1 inch ad. Radio spots can range from $6.00 to $11.00 per 30 second ad depending on the number purchased and TV can cost from $230.00 to $500.00 for a 30 second spot depending upon the time, the show, and the coverage area. Flyers can be mailed out, posters and signs can be put up, demonstrations can be staged, and numerous other methods can be used.

For an unusual product like SCMPR, it will be necessary to show it to the public. This can be done by displaying it at trade shows, fairs, and airports. TV ads can be purchased, but their expense will quickly reduce a small company's advertising budget. To get a wide viewing, it may be desirable to give away a robot or two to a place where it will be seen by a wide audience. Disneyland would be a good showplace.

With all the methods available, an exact budget can be hard to determine. Different methods will have to be tried and their effectiveness evaluated. For this product, 10% of the price of each robot would be a reasonable expense for advertisement until it becomes well known. For determining the cost of a robot, a flat rate of $200 from each robot will be assumed to go directly into advertising for a yearly total of $50,000.

H. Shipping

Once a robot has been produced and a customer attracted to buy it, it has to be delivered. The cost of shipping the robot will vary with the distance and quantity shipped. It can be absorbed into the price or charged as a separate item to the customer. For the computation of the price of the robot, $50 per robot will be included for shipping. This number will have to be adjusted once data is obtained from actual experience, but it should provide a good starting point.

I. Summary

Now that separate costs for producing SCMPR have been computed, an examination of the break down will show what the minimum price for each robot will have to be to break even. Listed below are the various costs and their total.

RENT	$300/month	$3600/year
UTILITIES	$220/month	$2640/year
PHONE	$100/month	$1200/year
LABOR	$4480/month	$53,750/year
INSURANCE	$417/month	$5000/year
ADVERTISEMENT	$4167/month	$50,000/year
	TOTAL	$116,190
	PLUS TOOLS & EQUIPMENT	400
	TOTAL	$116,590

The total cost for the first year of operation is $116,590 excluding parts. This is $466.36 per robot. Add $1311 for parts and $50 for shipping and the total cost per robot is $1827.36 or about $1830.

If the robot is sold direct from the factory, it could be sold for $1830. If it is sold through a retailer or a distributor, the price may have to be raised by 10% to 20%. If the company building them also wishes to make a profit on 250 per year, the price will have to be higher.

If the company could increase sales to 500 robots per year, it would realize a profit without raising the price of the robot. The price of the robot was based on two employee's salaries with only one employee building the robots. If one additional employee were hired to build robots, the output could be doubled while the cost of salaries would rise only 50%. This would bring the labor cost per robot down from $215 to $161, a savings of $54 per robot. If this quantity could be produced in the same factory with the only increase in cost being that from the increase in the number of parts ordered, the savings per robot would be $287. If only half this savings could be realized, the company would still make an additional $143 per robot.

To increase profits further, an increase in price and sales could be used together. Ideally, the price should be kept slightly below $2000 because of the psychological affect on the customer. A price of $1995 seems significantly lower than $2000 at first glance.

Other options for reducing costs include selling robot kits or plans. The savings on kits would be partially offset by the cost of preparing manuals and packaging. While plans are fairly inexpensive to produce, they require exact details and specifications and may be beyond the ability of

most customers to follow.

VI. SUMMARY

In the previous chapters, SCMPR was developed as a basic model. It is intended as a domestic robot, but it has many other potential uses. The basic model could be used for all of the following tasks without modification:

1. Carrying mail.
2. Carrying baggage at airports.
3. Heavy yard work.
4. Grocery carrying.
5. Carrying items from a stockroom in a store.
6. Carrying bricks at a construction site.
7. Others.

With the addition of circuit cards for sensors, attachments, or small modifications, SCMPR could be used for the following tasks:

1. Firefighting.
2. Military weapon.
3. Act as a pet.
4. Move snow.
5. Search for buried metal.

Other models could be developed for more specific tasks. A SCMPR could carry a large mechanics tool box, have a power jack as an attachment, and have connections for jump starting a car. For longer range a SCMPR could be powered by a portable generator. This would enable it to act as a pack mule and a mobile power supply. This model would be useful for long treks and for jobs that require walking and carrying materials, such as fencing. A smaller model could be made to roam indoors with a memory and ultrasonic sensors and could deliver packages.

While SCMPR was designed to be useful to the homeowner, its price will limit the market there. However, the possible uses for SCMPR suggests another list of potential customers. SCMPR may find a large market among small businesses and organizations. SCMPR also provides a useful basic robot for experiments and education at colleges and universities. (It could possibly be sold in the same manner as the Heathkit Hero robot.)

In conclusion, a simple robot is feasable with today's technology and can be made to be useful at a reasonable price.

BIBLIOGRAPHY

Archer Semiconductor Reference Guide, 1989 ed., Fort Worth, Texas: Radio Shack, A Division of Tandy Corporation, 1988.

Asimov, Isaac, I, Robot, Garden City, New York: Doubleday and Company, Inc., 1950.

Biber, C., S. Ellin, E. Shenk, and J. Stempeck, The Polaroid Ultrasonic Ranging System, New York, New York: Audio Engineering Society, October 31, 1980. 1696(A-8).

Cardoza, Anne and Suzee J. Vlk, Robotics, Blue Ridge Summit, Pennsylvania: Tab Books, Inc., 1985.

Chase, Richard B., and Nicholas Aquilano, Production and Operations Management: A Life Cycle Approach, 5th ed., Homewood, Illinois: Richard D. Irwin, Inc., 1989.

Committee for Economic Development, Work and Change: Labor Market Adjustment Policies In a Competitive World, New York, New York: Committee for Economic Development, 1987.

DeVinne, Pamela B., ed., The American Heritage Dictionary, 2nd College Edition, Boston, Massachusetts: Houghton Mifflin Company, 1985.

Evans, Bill, "The Lawn Ranger." Mechanical Engineering, June 1989.

Gove, Philip Babcock, Ph. D., ed., Webster's Third New International Dictionary of the English Language Unabridged, Springfield, Massachusetts: G. & C. Merriam Company, 1976.

Groover, Mikell P., Mitchell Weiss, Roger N. Nagel, and Nicholas G. Odrey, Industrial Robotics: Technology, Programming, and Applications, New York, New York: McGraw-Hill Book Company, 1986.

Hapgood, Fred, "Artificial Intelligence." Omni, vol. 11, no. 1 (October 1988).

Herbst, Diane, "In the Wake of a Modern Jason." Oceanus, vol. 32, no. 2 (Summer 1989).

Kangari, Roozbeh, and Tetsuji Yoshida. "Prototype Robotics in Construction Industry." Journal of Construction Engineering and Management, vol. 115, no. 2 (June 1989).

Minsky, Marvin, ed., Robotics, Garden City, New York: Anchor Press/Doubleday, 1985.

"Near Range Extender Modification," Polaroid Ultrasonic Ranging System Handbook Application Notes/Technical Papers, Cambridge, Massachusetts: Polaroid Corporation, date unknown.

The New Encyclopedia Britannica, 1982 ed. s.v. "Space Exploration."

Osman, Tony, Space History, New York, New York: St. Martin's Press, 1983.

Paula, Greg, "Robotics: Growing Maintenance Option for Utilities." Electrical World, May 1989, 65-72.

Plant, Malcolm, Dictionary of Space, Harlow, Essex, U.K.: Longman Group Limited, 1986.

Polaroid Corporation, Ultrasonic Components Group, Ultrasonic Ranging System, Cambridge, Massachusetts: Polaroid Corporation, September, 1987.

"Ranging Beyond 35 Feet," Polaroid Ultrasonic Ranging System Handbook Application Notes/Technical Papers,Cambridge, Massachusetts: Polaroid Corporation, date unknown.

"Robie Junior," Service Manual, catalog no. 60-2397, Radio Shack, (date unknown), 25.

Roth-Tabak, Yuval, and Ramesh Jain, "Building an Environment Model Using Depth Information." Computer, June 1989, 85-90.

Safford, Edward L., Jr., Handbook of Advanced Robotics, Blue Ridge Summit, Pennsylvania: Tab Books, Inc., 1982.

Shaiken, Harley, Work Transformed: Automation and Labor in the Computer Age, New York, New York: Holt, Rinehart, and Winston, 1985.

Shircliff, David R., Build a Remote Controlled Robot for Under $300, Blue Ridge Summit, Pennsylvania: Tab Books, Inc., 1986.

Simons,Geoffrey L., Is Man a Robot?, Chichester, West Sussex, U.K.: John Wiley and Sons, 1986.

Siuru, Bill, "Robo Warriors." Mechanical Engineering, May 1989, 82-87.

Stearne, Ivan G., How to Design/Build Remote Control Devices, Blue Ridge Summit, Pennsylvania: Tab Books, Inc., 1981.

SynPet Personal Electronic Technologies, The Anatomy of Newton, Hollywood, California: Bear Advertising, 1989.

Synpet Personal Electronic Technologies, Boise, to Terry Neville, Brookings, 31 October 1989.

Veritechnology Electronics Corporation, Heathkit/Zenith Educational Systems Division, "HERO 2000: The Knowledge Builder," Heathkit/Zenith Educational Systems, St. Joseph, Missouri: Veritechnology Electronics Corporation, date unknown.

Weiss, Rick, "New Dancer in the Hive." Science News, vol. 136, no. 18 (28 October 1989).

Williamson Jack, The Humanoid Touch, New York, New York: Holt, Rinehart, and Winston, 1980.