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ROBUST AUTOMATED INVENTORY CONTROL THROUGH COMPUTER INTEGRATED ROBOTICS*

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ABSTRACT

The obstacle of accurate inventory control plagues most facets of industry. The responsibility of tracking inventory is assigned to the operator and is accomplished by generating a paper trail of completed processes. The task of tracking various parts through a system can be efficiently accomplished via automated control through computer integrated robotics. The methodology for precise routing through a sophisticated system will be discussed in detail.

The integrated system includes a host computer system running a sophisticated database manipulation package, a gantry system, and ancillary equipment that includes a programmable logic controller (PLC) controlling several pieces of equipment, barcode readers used for human interface, and scales. The host system and gantry will be presented, and a canned package used for database manipulation will be described. The method of historical data collection will be demonstrated. An algorithm for determining permitted subsequent part routes with respect to the present part location will also be described in detail.

The integrated system will be presented and discussed to demonstrate the benefits of automated inventory control.

Keywords: Cell control, inventory control, robotics, computer integrated robotics, process control.

INTRODUCTION

Until recently, manufacturing at the Oak Ridge Y-12 Plant has been based on manual operation of processes, including transportation of parts between processes and inventory control. Many factors contributed to the decision to change this method of manufacturing such as more stringent inventory control standards, the desire for decreased exposure to hazardous materials, the need for more complete part histories, and the desire for consistent and efficient processing of all parts. A computer integrated manufacturing strategy was developed to move toward achieving these goals. Many operations that were once performed manually have been automated. A central data gathering/manipulation (host) system has been set up to work in conjunction with the automated operations. This host system has been programmed to control the routing of hazardous materials through a manufacturing cell. A plan was developed that would allow such an automated cell

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control system to be employed through the use of a gantry robot for material movement. The combination of host computer, relational database package, gantry robot, and operation-specific equipment yields a system that will meet many of the desired goals for parts manufacturing.

EXISTING FACILITY

In the existing facility, metal plates are processed for conversion into forming blanks. The facility includes storage; heat-treating salt baths; and equipment for water rinsing, shearing, and weighing parts. When possible, operations are conducted behind ventilated hoods. Many problems have been experienced with the existing system. Malfunctions due to equipment age are common and require routine operator and maintenance personnel entrance into the enclosed area (respirator and protective suit work). All equipment components are located inside the hood, which necessitates entrance for any kind of repair. Personnel exposure levels naturally increase with old, high-maintenance equipment, while regulatory requirements are becoming more conservative. The system is in need of refurbishing but cannot be out of service long enough to undergo a major refit. Safety concerns require that spacing between parts be maintained, which is accomplished by a combination of physical and administrative controls. Inventory tracking and individual part history are crucial to effective operations and are currently maintained via time-consuming manual manipulation of part cards and log entries.

INTEGRATED SYSTEM

An integrated system was developed to rebuild this facility to resolve the aforementioned issues. An integrated processing system with robot manipulation and computer supervision was selected.

An integrated system satisfies the above requirements and solves many of the problems associated with manual operations. A new, rugged process equipment and handling system (the gantry robot) provides highly dependable operations. Prime movers of equipment and major robot components are located outside or are serviceable outside the enclosure. Decreased operator exposure due to reduced accesses is realized, thus satisfying new regulatory requirements. The design consolidates enclosure, equipment, and manipulator to facilitate a timely installation period.

The facility is not designed to operate autonomously. Because of the complexity of advanced technology solutions and monetary concerns associated with automation, certain operations remain to be most feasibly executed manually, requiring operator manipulation through glove boxes after placement by the gantry. After completion of the manual operation, the robot resumes handling the material. It is essential that the gantry system and operator work in a symbiotic relationship. This approach also allows the operator and gantry system to continuously monitor each other, giving an added layer of protection against unacceptable movements of material.

Configuration control, inventory tracking, and individual part histories are maintained not only for documentation, but also as a means of sustaining process control while interfacing with the operator. A relational database is effectively used to preserve all needed data.

THE RELATIONAL DATABASE MANAGEMENT SYSTEM STRATEGY

The relational database management system (RDBMS) may be thought of as a subsystem that serves the integrated system in three ways:

1. It provides an orderly representation of the configuration of the system. For a manufacturing application, some of the kinds of configuration information that can be stored in the database include:

   a. Sequences. These usually define the safe and correct order for operations to be performed (temporal constraints).

   b. Permissives. These include other constraints such as the spatial separation of objects in the manufacturing area.

   c. Limits. These can be used to define the normal range of operational parameters such as temperatures.

   d. Access. The database can be used to define which commands or operations may be performed by different users or by users at different operating stations (barcode readers).

   e. Translation. Database tables can be used to define equivalencies between different logical representations used by different subsystems. For example, a translation table could be used to correlate the logical cell location "CONVEYOR 4" to physical axis coordinates for the robot subsystem.

It should be noted that configuration data are entered into the database prior to operating the integrated system. Once such data have been correctly entered, the tables are relatively static and require little maintenance.

However, because a general-purpose database system is so useful for storing many kinds of configuration data, it would not be unusual for the size of the tables used to configure the system to exceed the size of the tables used to store data collected during manufacturing (see item 2).

2. The database system tracks the current values of important operational data for monitoring the manufacturing environment. A table record exists for each object of interest in the cell or for each input signal collected. Status data that can be tracked include:

   a. The status of each piece of equipment.

   b. The current location of each part or subcomponent in the manufacturing area plus supporting status information such as the name of the most recently completed operation performed on that part. The completion of a significant operation such as using the robot to move a part from one location to another should cause status information to be updated.

   c. The current value of analog and digital inputs collected via instrumentation.

Note that as current values of operational data are monitored, they can be checked against constraints predefined in the configuration tables, with deviations triggering alarms, error reports, or other actions.

It can be seen that the sizes of the tables in which values pertaining to current cell status are also fairly stable, but the values of the fields within the status records change as often as necessary to reflect state changes in the modeled process (cell).

3. The database system also saves selected information for historical purposes. These records can be copies of or subsets of past status records, with an associated time stamp added to show the order of occurrence. So, the kinds of data saved in historical records is similar to those of "current" data:

a. Status of equipment, generally recorded on every change of status (not periodically).

b. Location and status of parts or important objects in the manufacturing area. The completion of a significant operation such as the movement of a part by a robot from one location to another should cause a history record to be added.

c. Data collected from instruments. Digital values can be recorded (with time stamp) on each change of state; a new history record is typically recorded periodically for each analog value of interest.

Unlike the database tables that show the current state of operation, historical data records are added to tables but never modified. Obviously, unlike the other kinds of data tables discussed, historical data tables in the database grow over time and must be archived whenever the storage capacity of the computer system is approached.

Because these important functions are built around a powerful and widely used relational database package, the traditional DBMS tools permit the system to be easily configured, monitored, and analyzed afterwards for manufacturing and accountability purposes. Such tools include a variety of interactive query languages, database query language preprocessors, report generators, forms, and application generators as well as tools for maintaining and optimizing the database structure itself. The vendor of the system provides "front-end" applications that interface the various pieces of equipment (e.g., robot, conveyors, scales) to the integrated system.

The following summary shows some characteristics of the three major kinds of database tables useful for supporting an integrated control and tracking system.

Data function	Record creation	Record modifications occur	Table size
Configuration	In advance (manually entered; must be present)	Infrequently	Static
Status monitoring	Upon state changes or other events (automatically maintained by applications)	Frequently	Static
Historical	Upon state changes or other events	Never (must be archived)	Increases

INTEGRATED SYSTEM OVERVIEW

The cell control system with a gantry robot was chosen for its capabilities as an effective means of transporting hazardous materials, the ease of database manipulation through menus and barcode readers, and the quality control attained through database queries used to obtain the next permitted step for a given part in the cell. The system consists of a host cell controller, an overhead gantry robot, and ancillary equipment used inside the cell. Parts are transported into the system via a conveyor at the entrance of the cell. Part movement is initiated by using a predetermined route to ascertain the next allowable movement of a part. The part number itself is used to demarcate the routing algorithm that will be used to guide the part through the cell. The amount of time the part is located at a station is stored in the database. Upon completion of all operations, the part exits the cell and is removed from the list of open part numbers. Accurate operation of the host database is the key to proper functionality of the entire system.

THE HOST COMPUTER SYSTEM

The host computer system consists of a Microvax II (trademark of Digital Equipment Corporation) with 16-MB memory, a database manipulation software package, an Ethernet (trademark of Xerox Corporation) connected to the gantry's personal computer (PC), two terminal servers, and a cell control software package. See Figure 1 for a layout of the control system test bed.

The cell controller serves as a real-time monitoring and control system used for manufacturing operations. Through a human interface, information about any part in the system can be displayed by using the relational database cell control system.

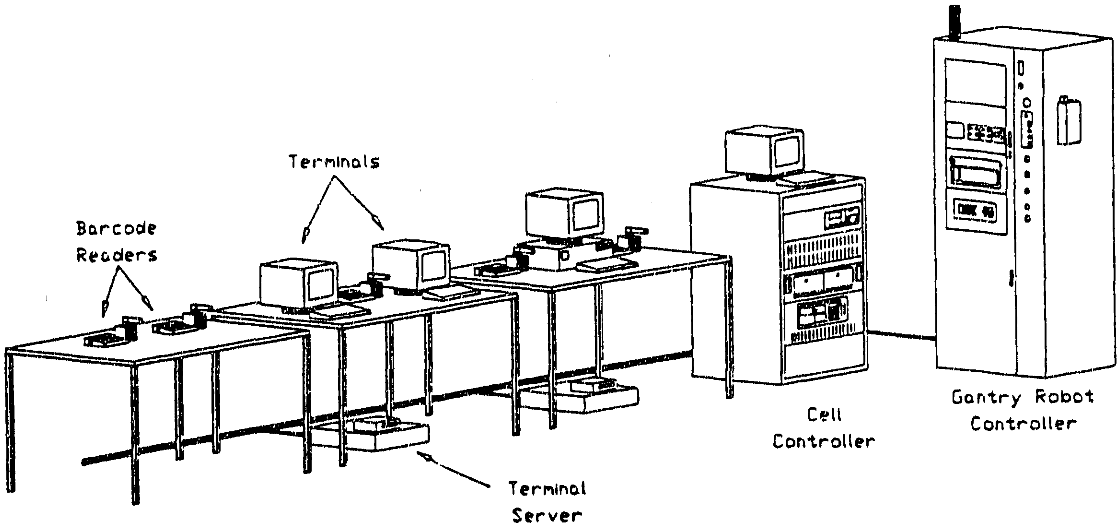

Figure 1 – Cell Control System Test Bed Layout.

CELL CONTROL SYSTEM

The cell control system serves as the supervisor for the cell. The human interface consists of a group of menus used to display the operator's options. The operator views items such as part location, present step executing, previous step, and completion code. The operator also has the option to generate reports as needed.

Navigation through the cell is determined by a technique in the cell control package called table programming (state machine). Database tables are used to determine which next allowable step will be executed for a part on the basis of input from operator-manned barcode readers. Unique routes can be generated for each part type maneuvered through the cell. Tables are also used to set preexisting conditions necessary for a part to move to a given location. For example, if a certain area in the cell must be vacant before a part can enter that area, the tables can be used to ensure that all stations in the given area are unoccupied before the step to move a part into the area can be initiated. Stations communicate to the cell control system via a PLC or Ethernet.

ETHERNET

Equipment inside the cell communicates to the cell controller through terminal servers attached to Ethernet. Some stations are connected directly into the terminal servers, while others [which are exclusively controlled by digital input/output (I/O)] are routed through the PLC. The Ethernet communications protocol is also used to allow communications between the cell control system with its associated equipment and the gantry robot.

GANTRY CONTROL

The robot controller communicates with the host computer, referred to as the cell controller, and cell equipment connected through terminal servers. The robot controller, cell controller and cell equipment are physically linked by an Ethernet coaxial cable. Software communications are established between the robot controller, the cell controller, and cell equipment via DECnet and DECnet-DOS software and hardware (1). See Figure 2 for a pictorial representation of the physical cell mockup.

DECnet

DECnet (trademark of Digital Equipment Corporation) is a combination of software and hardware communications products that enables computers and other smart devices to participate in a computer network. The participants in the work cell network are the robot controller, the cell controller, and the cell equipment.

The hardware communication products included in the work cell network are an Ethernet coaxial cable, four transceivers and two termination caps. The software communication products consist of protocols that govern internal software communications and utilities that allow remote file access, resource sharing, and network management.

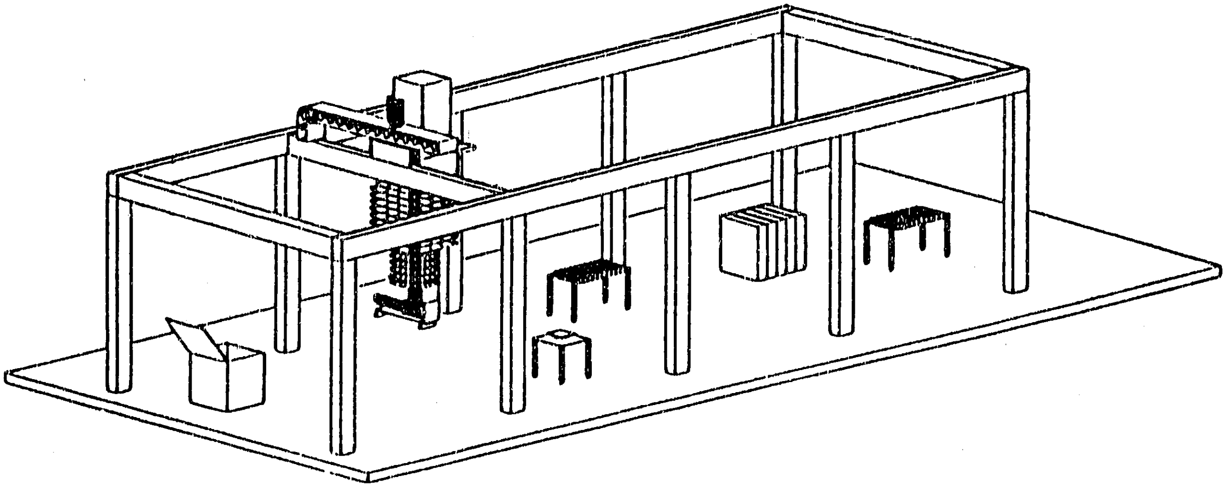

Figure 2 – Physical Gantry and Cell Mockup.

DECnet-DOS

DECnet-DOS (disk operating system) is a DECnet software package that allows PCs running the MS-DOS or PC-DOS (trademarks of Microsoft Corporation) operating system to participate in a DECnet network (2). The architecture of the robot controller is International Business Machines (IBM) PC/AT compatible and uses MS-DOS as the operating system. A DECnet-DOS board is installed for network communications.

Figure 3 depicts the work cell network with communication hardware: **termination caps, transceivers, Ethernet coax;** and communication software: **DECnet and DECnet-DOS.**

ROBOT

The robot is a five-axis direct current servo-controlled gantry. Usually referred to as a gantry robot, the robot performs "pick" and "place" operations between cell equipment such as baths, storage racks, and conveyors.

The gantry robot consists of a support structure, a bridge that moves on the structure to provide X travel, a carriage that moves on the bridge for Y travel, a telescoping mast mounted on the carriage for Z travel, and two rotational axes mounted at the bottom of the telescoping mast. The first rotational axis, theta 1, is mounted at the end of the Z axis and provides rotation about the Z axis. The second rotational axis, theta 2, is mounted on theta 1 to provides rotation from vertical (3).

As part of the work cell system, the robot is connected to the robot controller, which participates in the work cell network. See Figure 4, which depicts the robot's axes and robot controller.

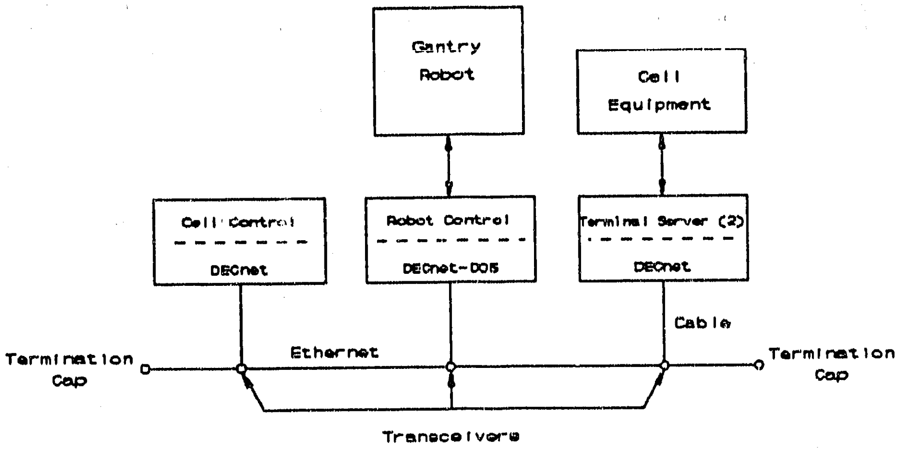

Figure 3 – Work Cell Network With Communication Hardware and Software.

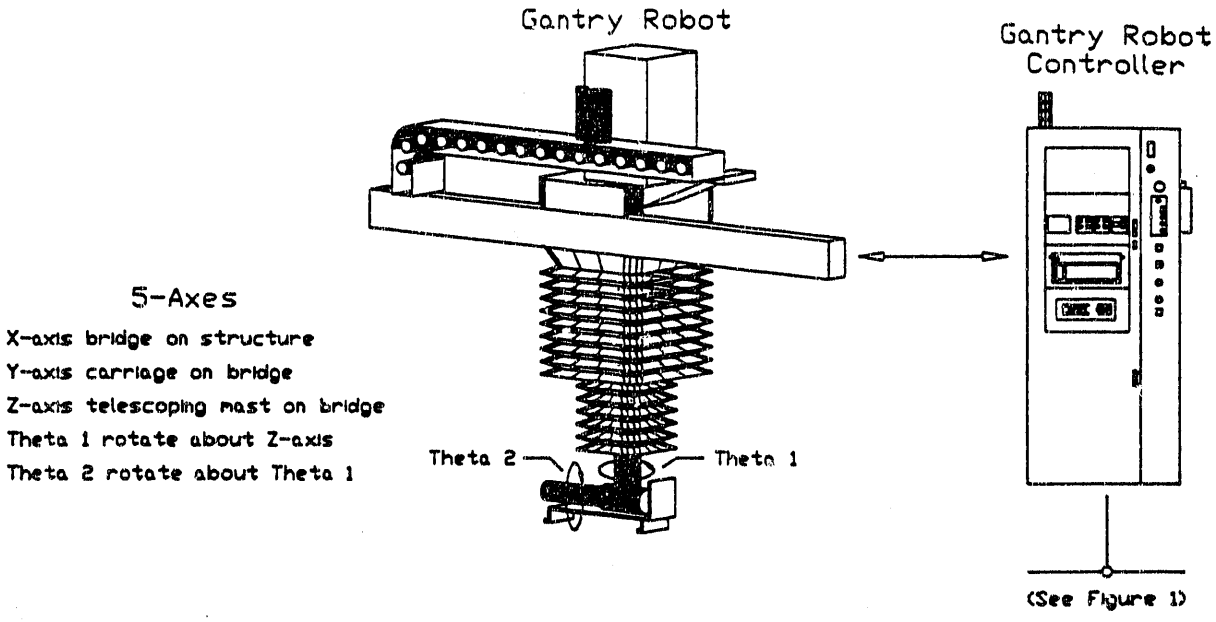

Figure 4 – Gantry Robot's Axes and Robot Controller.

SYSTEM CONTROL

The robot controller controls the motions of the gantry robot as well as multiple serial I/O ports and multiple channels of digital and analog I/O. The IBM-AT supervises separate trajectory processors and individual servo central processing units (CPUs) for the five axes. This three-level multiprocessor design consisting of the IBM-AT supervisor, trajectory processors, and servo CPUs, make possible simultaneous motion control of the gantry robot's five axes while I/O processing is in progress.

The robot controller also provides three modes of operation: automatic mode, manual mode, and teach mode. Automatic mode provides for the complete control of the robot's motions, axes, and I/O by applications programs written in "C". Manual mode allows for complete control of the robot's motions, axes, and I/O with a hand-held teach pendant. Teach mode functions in manual mode are used to assign robot position and orientations to point names created in the application programs.

Figure 5 depicts the three-level multiprocessor design of the robot controller consisting of the IBM-AT supervisor, trajectory processors, servo CPUs, and the three modes of operation.

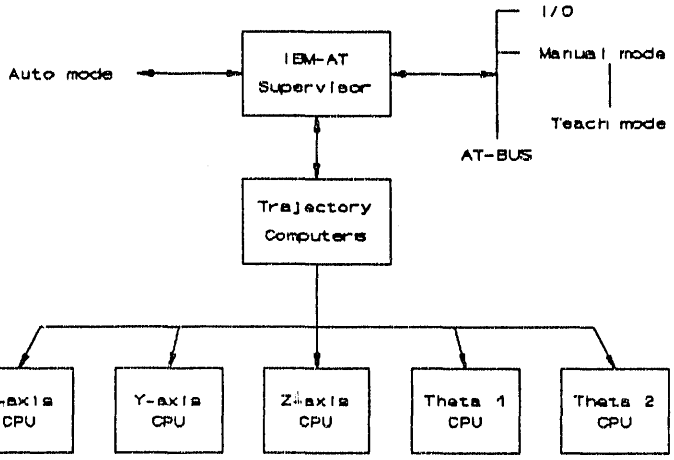

Figure 5 – Robot Controller Architecture.

ANCILLARY EQUIPMENT

Several pieces of equipment are integrated into the cell control system. Barcode readers are used for operator input of commands, part numbers, and for final validation of part movement at a station. The barcode readers are used to keep the operator in the control loop. If the operator decides a given part should not be placed in the predetermined location, an abort can be entered at the barcode station and the gantry will move to a park position and wait for a "move to storage" command to be entered. The storage locations are used to allow a part to cool after the saltbath operation or to store a part while the next station in the part's route is occupied. Other equipment includes saltbaths, water rinse, conveyors, shears, leveler, and weigh scales. A PLC is used for all digital I/O in the system. Almost all activities are directed by the cell controller. Maintaining control from the cell controller helps ensure that central management controls all movement inside the cell.

SUMMARY

Computer integrated robotics can be used to manipulate hazardous parts through a manufacturing cell safely and efficiently. Configuration control, inventory tracking, and individual part histories can be maintained not only for documentation requirements but also as a means of maintaining process control while interfacing with the operator.

The sequencing of a part through the cell is determined by the correct combination of operator entry and cell-control database validation. Part movement validation is no longer left solely to the operator. A series of rigorous database queries are used to determine whether an operator-entered part-movement request is valid. Checks and balances are also placed on the gantry. A part will not be picked up or placed at a station until the operator has pushed a barcode key to verify that the given pick/place is correct.

Gantry movement of parts satisfies safety requirements because the operator will not be subjected to hazardous fumes from the saltbaths and water rinse. The operator will handle the part only when a manual operation is necessary, which significantly reduces the operator's exposure time.

A database table can be used by the operator to locate all parts in the cell, their previous steps, completion codes, and their current status.

Old, malfunctioning equipment is replaced by new state-of-the-art equipment, which will increase reliability and reduce costs because fewer maintenance problems will be experienced.

In conclusion, computer integrated robotics can be used effectively to achieve inventory control, satisfy safety requirements, and maintain part histories for all parts in a manufacturing cell.

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