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Control Software for an Advanced Sensor-based Robotic Assembly System

abstract

Westinghouse's Standard Electronic Assembly Station (SEAS) is an advanced robotic assembly system for printed circuit board production. One of the composite stations, the Axial/Radial/Can insertion station, consists of a host computer, robot and vision systems, as well as mechanical devices. The purpose of the host software is to monitor and control the insertion of axial-, radial-, and can-type devices into printed circuit boards on a real-time basis, with minimum human intervention and maximum successful insertions.

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INTRODUCTION

An automated CAD/CAM system for manufacture of defense electronics has the cost/benefits of improving quality (as determined by first-time through-yield), reducing product cost, and aiding in meeting production schedules. Westinghouse Electric Corporation is currently implementing advanced CAD/CAM technology in their "factory of the future" at College Station, Texas. The initial focus of this factory is batch manufacture of printed circuit boards (PCB's) to Mil-Spec quality standards. This system (Figure 1) includes the use of computerized production planning, scheduling systems, material requirements planning, and inventory control, as well as computer-aided design systems, CAD data postprocessors, and robotic assembly and automated material handling systems. This paper deals not with the overall system design or operation (documented in Reference 1), but with the software design of the robotic assembly system known as the Standard Electronic Assembly Station (SEAS). SEAS contains several components (Figure 2) designed to assemble a specific family of electrical components, e.g., dual-in-line packages (DIPS), resistors, capacitors, and transistors (Figure 3). The assembly stations of SEAS (Figure 2) are provided components in standard kits by the Material Accountability and Robotic Kitting system (MARK), and integrated with MARK by data transfer and similar Work Center Controller designs. Work flows through the SEAS system from robotic assembly, computer aided manual assembly, wave soldering, and back to computer aided manual assembly and inspection data entry. This paper describes the software design of the Axial/Radial/Can (ARC) module, whose major design goals were:

1. Insertion of resistors, capacitors, and transistors into PCB holes with a minimal diametrical clearance of .005 inches.
2. The ability to handle different PCB styles with little set-up time.
3. The ability to accommodate variability in lead forming dimensions.
4. The ability to accommodate a wide dimensional range of axials, radials, and cans.

Designed for highly accurate assembly, the ARC module is a complex robotic system. The robot controller reacts to its force sensors, handling each part insertion on an individual basis. The entire system is CAD data driven, and able to adapt to any printed circuit board style by the contents of its data file (called a RIS - Robotic Instruction Set). The high level language available in the robot and vision controllers allows real-time update of data, both from the RIS and from the environment, as opposed to a point-to-point 'taught' system. The computer software is composed of approximately 6900 lines of Fortran code, and includes a Work Center controller interface, an elaborate calibration routine, an Insertion Sequencer program, as well as various other routines and interfaces which allow real-time insertion of discrete components in an unmanned environment.

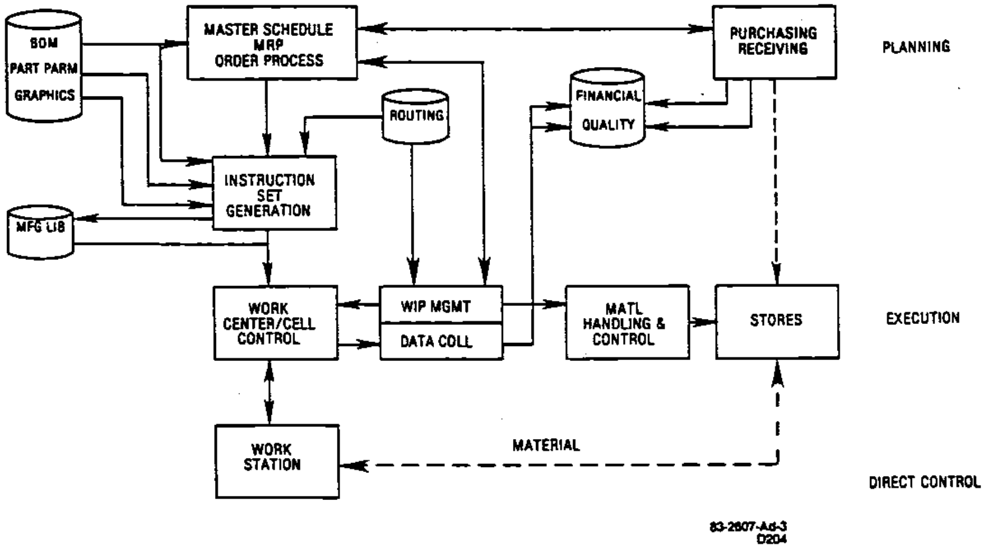


Figure 1. The computer-integrated manufacturing control architecture has been structured with three levels.

BACKGROUND

The Axial/Radial/Can insertion substation is devoted to the insertion of preformed axial, radial, and can-type devices into printed circuit boards (Figure 3). It consists of a Hewlett-Packard A600 memory-based computer, an Automatix AID-600 robot arm, an Automatix AutoVision 4 vision system, as well as an Aerotech XY table and a Universal cutting mechanism (Figure 4). The programmable end-effector on the robot arm was designed by Westinghouse specifically for this application. All the software on the host (HP A600) computer is dedicated to monitoring and controlling the component insertion process, while interfacing to the Work Center Controller computer for routing and exception information. Communication to the robot and vision controllers is via an RS-232 link, and to the XY table and cutter mechanism via discrete lines from a Parallel Interface Card.

FIG. 2. SEAS ARCHITECTURE

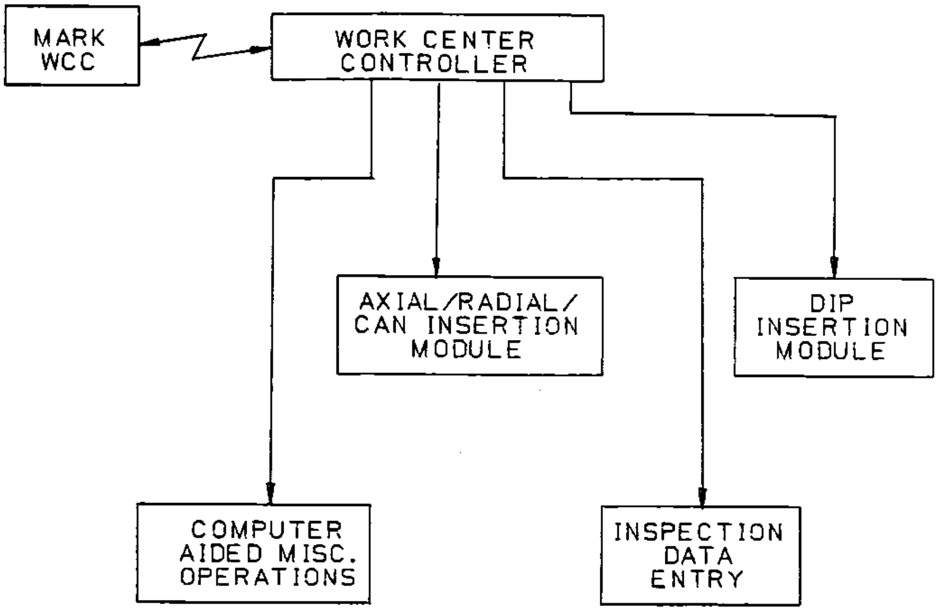
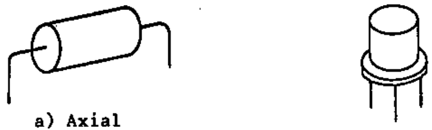


Fig. 3 SEAS Family of Components



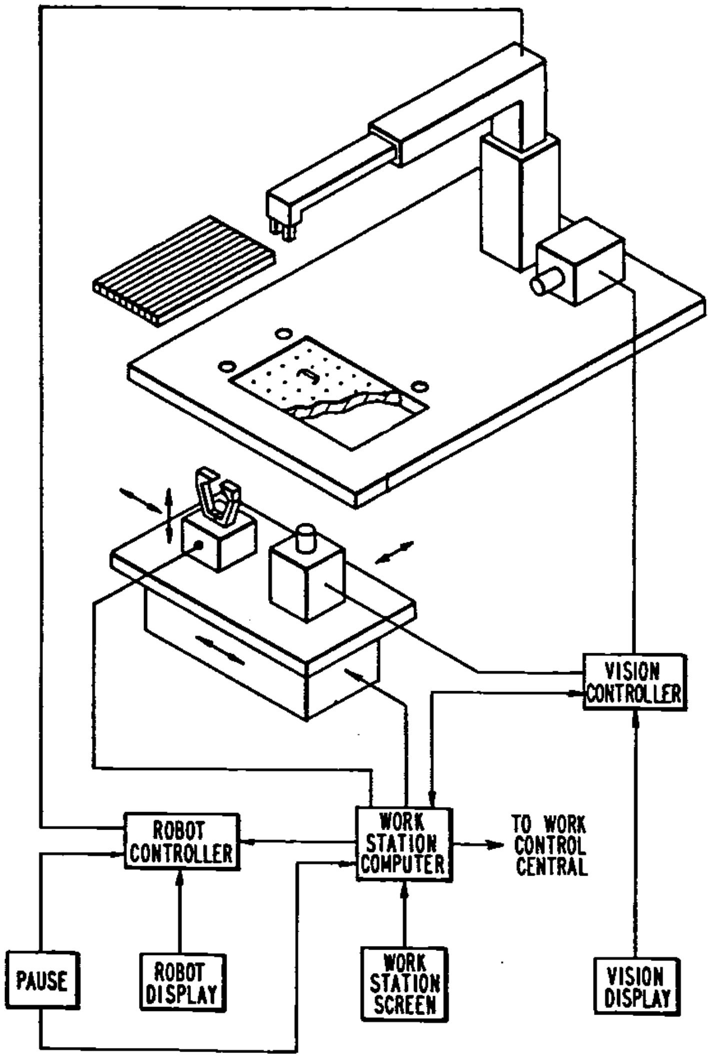
a) Axial

b) Can

c) Radial

d) DIP

Fig. 4 ARC Assembly Station



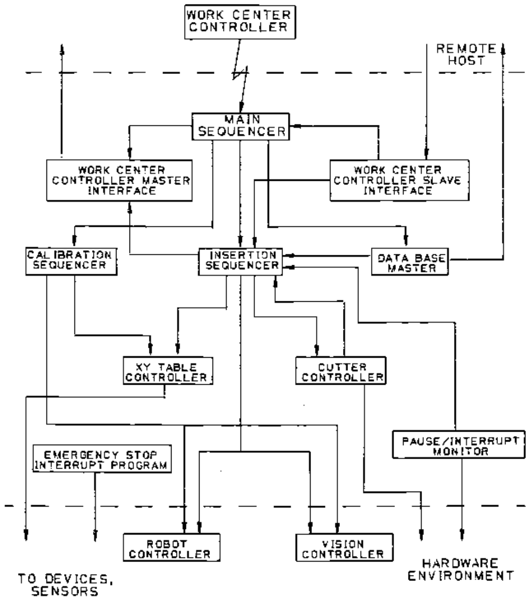


FIG. 5. SOFTWARE ARCHITECTURE

The host computer software is arranged hierarchically; that is, flow of control passes from programs with more general applications to those dedicated to a particular device or function during the insertion process (Figure 5). To maintain modularity and flexibility a library of subroutines was developed as a communications package, enabling all but the most dedicated programs to view external devices as 'black boxes'. Also included are a pair of interface programs for asynchronous message transfers to the Work Center Controller. This enables the work station to devote itself to board assembly, relatively independent of events in the rest of the automated factory.

PROCESS DESCRIPTION

In a manual production environment, data is obtained almost exclusively from assembly drawings and bills of materials. Each technician must cross-reference these papers with materials presented to him during the assembly process. In an automated environment, all of this data must be captured in electronic form; thus, a 'front end' system is necessary. All information is obtained from various files in various formats, and finally coalesced into a form processable by the host computer and robot controller.

An Engineering Data Library is created on an IBM 4341 which is composed of distinct subsets - the Part Characteristics file (contains component specific information - dimensions, forming shape codes, part numbers), the Standard Parts List and Microelectronic Device file (contains electrical verification information), and the Engineering Bill of Materials file (control information specifying which parts are to be used for assembly of a specific printed wiring assembly). Used in conjunction with this library are Drill Tapes (contains board geometry data) and an Electronic Component Library for the digitization process performed on a Computer Vision system. Using the CV system, the operator can capture design drawings so that this information can be used to generate robot instruction sets. Important to note, the digitization process was used prior to the development of the CAD system. Most data can now be drawn directly from a CAD data base for CAD designed boards. Once the data is collected, a Post Processor program is run on the IBM 4341. This program determines the X-Y locations of parts on the board, an optimum insertion sequence, cut and clinch approach and orientations, kitting sequence, and also flags which parts cannot be robotically inserted.

Created at the same time is a RIS for the MARK module, which includes a robotic kitting station. Given the RIS, the MARK system robotically prepares a component kit for the circuit board to be assembled. The resulting components have their leads trimmed and bent to the desired form. All the components for one particular board are then placed in a standardized component kit carrier. This kit is used by the ARC station in production of the printed circuit board. Additionally, any part shortage information is passed along, eliminating attempted robotic processing of missing components at the ARC station.

Given the data file for a particular board style, the component kit, and printed circuit board, component insertion can commence at the ARC station. A basic flow chart of the process is provided in Figure 6.

The Insertion Sequencer program sends the robot controller part physical characteristics, part pick-up location, and insertion information, which signals the robot to acquire the part from the kit. Force sensors on the end-effector are monitored by the robot controller, indicating presence or absence of the part, and allow the robot to accommodate variance in the part dimensions. The part acquisition process is performed exclusively by the robot controller, leaving the host computer free to perform other system functions.

Concurrent with part acquisition, the Insertion Sequencer communicates with the XY table and vision controller to accurately locate the holes in the printed circuit board where the component will be inserted. Locating these through-board holes on a part-by-part basis allows a real-time update in the part data should the board shift during the process. The hole centering process uses the below-the-board camera; backlighting above the station allows light to pass through the holes in the printed circuit board, which enables the vision system to capture their image. The resulting vision offsets are used to modify the target locations provided by the RIS.

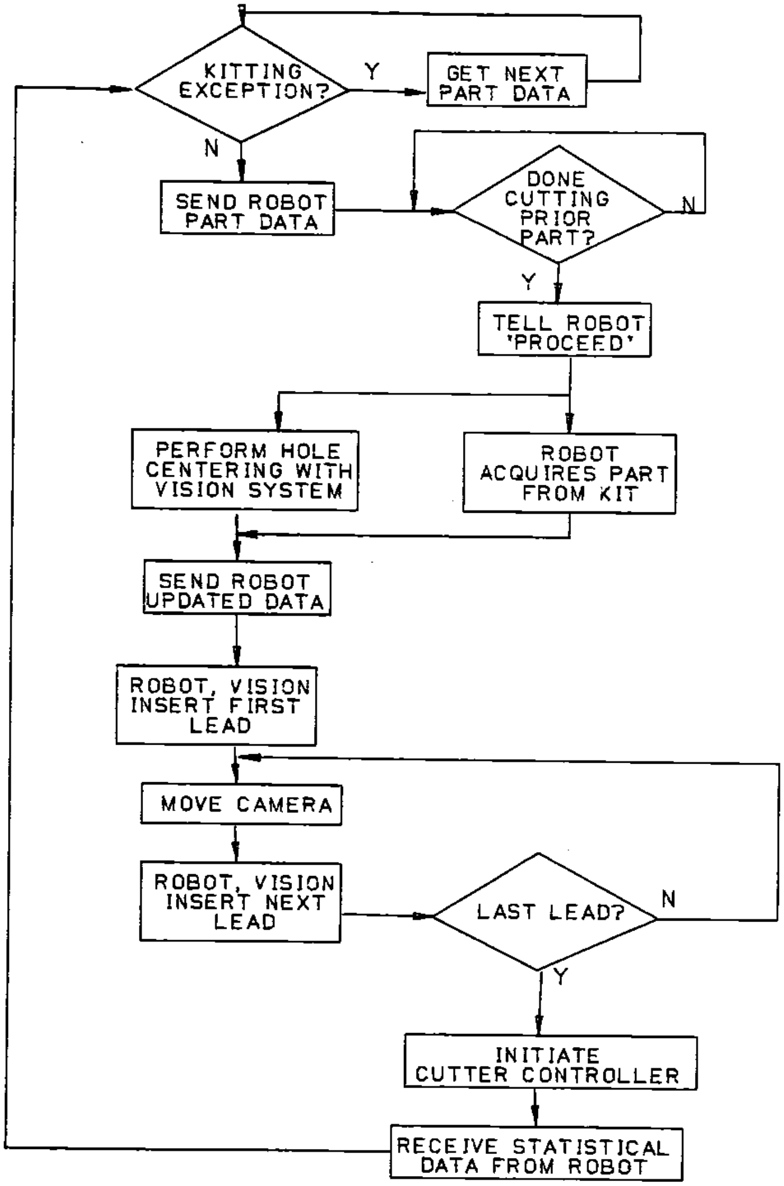


FIG. 6. INSERTION PROCESS FLOW

This updated data is then sent to the robot controller, enabling smooth continuation of the insertion cycle. At this point, the host computer software passes control to the robot and vision systems, which communicate in a tight servo loop for lead-by-lead insertion of the component.

Each lead on the electrical component is cut to a different length so that one lead is inserted at a time. The vision system shines a light through the hole in the circuit board, attempting to locate the lead tip by the light reflection. If the lead is not seen, the robot moves in a tight spiral search pattern, until the lead is seen by the vision system, indicating that it is directly over the hole. Load cells on the board fixture are monitored by the robot controller, indicating probable contact of the leads with the board. Attempts are made by the robot to compensate for bad part formation and part misalignment relative to the gripper fingers by relying on lead compliance, sensor feedbacks, and vision data. At the end of each insertion cycle, the robot controller passes information reflecting use of these compensation techniques to the host computer for statistical purposes.

When the robot determines that it has successfully inserted the component, the host computer software initiates the cut and clinch of the leads on the components, thereby affixing the parts to the board. During the cutting process, the robot sends the statistical information gathered, and the host computer sends the next set of part acquisition information to the robot controller. When the cutting is completed, the cycle begins again, until the last part has been processed.

The software in the host computer (as well as that of the robot and vision controllers) is written to accommodate producing any number of boards of any board type; all that is necessary for the automatic assembly is the kit of preformed components, a palletized board, and a data file. In this manner, 'work orders' of only one board are viable, or high-priority work can readily be introduced.

UNIQUE AREAS

When designing the host computer software, several features of the HP A600 operating system were utilized. As control passes between several programs, so does the need for status, directives, and system constants. Since the host computer is memory-based, there can be no interprocess communication via files. Thus, the interprocess communication goes on in three ways.

A shared common area called System Common is used; status bits and error flags are set, and constants passed between programs. A map of the offsets into this area is included in each program, enabling the software to refer to the variables by logical name, with no knowledge of the physical layout of this common.

Similarly, another globally available area known as EMA is used to store all the data necessary for the building of a particular board style. In this manner, a download of the data is initiated at the beginning of the boardbuilding process, and the Insertion Sequencer program can readily reference this information, requiring only memory-access time.

Two final aspects of the operating system are used for interprocess communication; local program-to-program communications use a feature known as Class I/O, and internodal communication uses HP supplied Program-to-Program communication techniques. Class I/O enables any number of programs to communicate in an asynchronous fashion. Should a program desire to write a message to another, it can do so with the assurance that the message will be queued, and subsequently continue with its own processing. When the other program(s) desire this information, they can then receive the transmission. A status code reflects if there is indeed a message pending; if there is not, the reading program is not left in a wait state for the I/O, but can continue its own processing, and perhaps check again later.

HP-supplied Program-to-Program communications are similar, though they work across a computer network. A pair of dedicated programs exist both on the substation controller computer as well as the Work Center controller computer. A Master program on the substation controller passes messages to a Slave program on the Work Center controller, and vice versa. Messages from the Work Center controller can then be processed by the substation at a time that is logically convenient to the building process. This eliminates the need for mailbox polling or file communications, decreasing the overall communication time.

One final facet of this software system is the built-in error recovery techniques utilized. This system was designed with two goals foremost: first, to run in an unmanned environment, and second, to maximize the number of successful insertions with a minimal insertion cycle time. Though seemingly at odds, these two goals seem to have been met. The station can easily run unattended, with a statistics file kept logging each part processed by the system, and any exceptions or errors encountered.

The second goal, however, proved the most difficult to implement. By utilizing the above communication techniques, an elaborate communication scheme was incorporated in a real-time system. A set of calibration techniques was employed to compensate for the various reference frames of the tools in the system, as well as any board warpage or misalignment. The use of the vision system allows for a wide tolerance both in the part forming as well as the kitting process.

Additionally, a technique of lead characterization is used for those components robotically acquired by the component body (radial and can devices) where there is minimal control over the location of the lead tips. This characterization process enables the robot to calculate the X-Y-Z location of the lead tips relative to the part body, compensating for inaccurately formed leads. Tight lead-to-hole diametrical clearances necessitate the use of external sensing devices and error avoidance techniques. Repetitive processing errors often result in recalibration of the various tools within the system in an attempt to trap any board, light, or camera shifting or misalignment.

SUMMARY

Out of the need for high quality assembly of printed circuit boards arose SEAS. Shortly to be placed in a production line, the ARC station has proven highly reliable in the pilot line testing phase. Out of the fifteen production boards built by ARC, insertion reliability was greater than 96%. Our current part insertion cycle time is approximately 34 seconds, which will be reduced to 24 seconds in the next generation of hardware and software designs.

ACKNOWLEDGMENTS

I would like to acknowledge the team of engineers who developed and implemented the ARC module -- Bruce Krein, William McConnell, Daryl Mileaf, and Dave Ferris. Their high level of expertise and willingness to assist made software design and integration as painless as possible, considering the nature of the task. Additionally, the foresight and planning of Dr. Robert Stewart helped to get the SEAS project, and ARC in particular, off of the ground and onto the shop floor.

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