ROBOTICS: APPLICATIONS FOR THE GRAPHIC ARTS

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Abstract: The development of the science of robotics is briefly described with emphasis on university research advances. The Robotics Institute at Carnegie-Mellon University is described in some detail with brief descriptions of the six robotics laboratories currently established and operating: intelligent systems laboratory; vision laboratory; sensor laboratory; mobile robots laboratory; flexible assembly laboratory; and flexible machining laboratory. The current applications of robotics in the graphic arts to palletizing operations is briefly reviewed. Current research for future robotics applications in the graphic arts are described in some detail. These are : press process analysis; printed circuit inspection; press-to-truck distribution control; and plant management systems. Some potential future applications of robotics to the graphic arts are suggested together with a review of the likely growth of the robotics industry.

Introduction

The robot industry has grown from small beginnings (only 200 robots were in use in the United States in 1970) to become a major growth industry (over 5000 in use during early 1982) that many claim heralds a new industrial revolution.

The science of robotics and the associated field of artificial intelligence have also grown rapidly as areas of research at universities around the world. Several computer programs now exist that are capable of matching humans in "thinking" activities. In some specialized cases, the computer can outperform the human.

Industry in general and the printing industry in particular have not yet felt the impact of robotics

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technology. However, most observers claim that the key to future improvements in productivity is the field of robotics, and they predict an explosion in robotics use in the coming decade.

The printing and allied industries are likely targets for the applications of robotics both because of the considerable materials handling requirements, and the relatively high-level problem solving involved in most stages of the manufacturing process. This paper is concerned with current robotics technology that is applicable to the printing industry as well as "blue sky" applications that may be possible in the future.

Robotics - Background Information

The use of programmable mechanical devices dates from 1801 when the programmable loom was designed by Joseph Jacquard. The next 150 years saw the introduction of a number of programmable machines, all of which could be set to perform a series of tasks either faster, more accurately, or safer than humans. None of these machines had any of the human senses - they were essentially automatic machines that could be reprogrammed to perform a similar series of operations. These early machines were the forerunners of today's robots. It took the invention of the computer in 1946 to advance the science of robotics from that of automatic machines to "intelligent" devices that have rudimentry forms of some human senses.

The pioneering work in the 1950s at Carnegie Institute of Technology (now Carnegie-Mellon University) and the RAND Corporation by Allen Newell, Herbert Simon, and J.C. Shaw established the foundation for modern artificial intelligence (AI) research (Hunt 1975). AI is the attempt to program computers to simulate human intelligence. These computers, in turn, can then be used to drive various mechanical devices, hence creating an intelligent machine.

Newell and Simon developed the heuristic method of computer problem solving, which basically involves guessing the nature of a solution and then proving that the guess is correct. The protocol method, where a human "thinks out loud", is used as a basis for programming the computer. Some programs have been developed for the computer to grow "smarter" through successive problem solving. AI has been used in applications ranging from games like chess and backgammon to medical diagnosis.

The leaders in AI research are also the leaders in robotics research. In the United States they are Carnegie-Mellon University, Massachusetts Institute of Technology and Stanford University.

The first programmable robot was patented in 1954 by George Devol. These patents formed the basis for Unimation, Inc. the largest manufacturer of robots in the world. The other major U.S. companies in the robot business are Cincinnati Milacron and Prab Robots. New entrants into the field include Westinghouse, General Electric, IBM, Bendix, and United Technologies.

European and Japanese companies are also very active in the robot industry. European companies include: AKR, Traalfa, ASEA, Kuka, Mouldmation, Pendar, and Sormel. Japan is generally acknowledged as the world leader in the use of robots - almost 20,000 were in use by 1980. Japanese companies making robots include: Hitachi, Fujitsu Fanuc, Nachi, Taiyo, Marol, Seiko, Yaskawa, and Mitsubishi (Donlan 1982).

The robots currently in use are the first generation in robot development. These are essentially mechanical arms with very few and very limited senses. The second generation robots, currently under development, will have vision, hearing, speech, touch, and thinking abilities. The third generation robots will include the capabilities of the second generation devices and add mobility.

The science of robotics, as the field is now called, involves the disciplines of computer science, cognitive psychology, mechanical engineering, electrical engineering and industrial administration. Most universities would classify robotics as a branch of artificial intelligence. Professor Newell of CMU has described robotics as the welding of artificial intelligence to the control of energy. This description has been adopted as a working definition of robotics for this paper.

The Carnegie-Mellon University Robotics Institute

The largest university based research into robotics is being conducted by the Robotics Institute of CMU. The Robotics Institute was established late in 1979 with a yearly budget of $1 million. By 1982 the budget of the Institute had grown to $5 million, 10,000 square feet of robotics laboratory space was in use, and the staff had grown to 75 professionals (25 of these are Ph.D. research scientists and faculty members). The major financial sponsors of the Robotics Institute are Westinghouse Electric Corporation and the Office of Naval Research. Other contributors include Rockwell International, Digital Equipment Corp., IBM, and Siemens.

The basic research being conducted by the Institute is divided among six laboratories. The laboratories and their goals are discussed below (adapted from "The Robotics Institute - An Introduction," 1981).

1. Intelligent Systems Laboratory. Research is done in the areas of knowledge representation and acquisition, planning and problem solving, model analysis, and user interfaces. The lab is constructing an intelligent management system which will sense, model, manage, and optimize the running of the factory at both the plant and managerial level.

2. Vision Laboratory. The vision laboratory is concerned with the development and application of techniques for use of non-contact visual information for robotics. Visual non-contact sensing and recognition (including infrared, x-ray and other electromagnetic radiation) is one of the most essential capabilities for versatile, intelligent, sensor-based robots in the future.

3. Sensor Laboratory. Sensor system components currently under examination concern tactile sensors (touch, force and vibration), laser sensors for three-dimensional imaging, acoustic sensors for voice systems, and chemical sensors. The central aim of the laboratory is the development of multi-sensor systems coordinated by a shared machine intelligence.

4. Mobile Robots Laboratory. Research in the mobile robots laboratory is concerned with the development of techniques and hardware for autonomous and semi-autonomous robot rovers. Such rovers are needed for both natural environments (on the planets and under the sea, for example) and artificial ones (on the factory floor).

5. Flexible Assembly Laboratory. The flexible assembly laboratory provides a facility for experimentation with robotic approaches to assembly of batch-produced parts. The intent is to develop "flexible automation" systems that are practical for much smaller batches than

are currently feasible. If the assembly system is coupled to appropriate data processing equipment it would make possible units-on-demand-custom assemblies of units with selected styles and options.

6. Flexible Machining Laboratory. At the center of the lab is a large industrial robot, surrounded by machining equipment in a conventional cell arrangement. The long-range goal is the development of a parts-on-demand system, in which all stages from parts design to final testing are coordinated and optimized by the machine.

Present Robotics Applications in the Graphic Arts

The present uses of robotics in the graphic arts are quite restricted. The main application is for palletizing, a limited materials handling application that transports bundles of finished product from a finishing line to a pallet.

The problems in using human workers for palletizing include absenteeism and worker injury. Replacement robots cost about $80,000 each and "work" for $6-8 per hour. Both reliability and lower costs are cited as advantages for using robots for palletizing tasks. These robots would be suited to the large "manufacturing" printer that produces a consistent product in a relatively small bundle. Robot arms have difficulty in handling large stacks of unbundled printed matter as well as large format printed paper or board.

Very few companies in the United States are currently using robots for palletizing printed material. The experience of these companies has progressed little beyond the breaking-in stage, hence it is not possible to make an accurate assessment of their usefulness at this time. However, because of the physical risks to the human worker, as well as the relatively high absenteeism (probably due to boredeom), the palletizing job seems well suited to a robotics solution. The solution could be either in the form of a supplementary robot arm or a robotized manufacturing machine.

CMU Research for Robotics in the Graphic Arts

Carnegie-Mellon University has a long association with the printing industry that dates back to 1913. The first degree-level program in printing, the Printing Management program, has evolved over the years into the Graphic Communications Management program of today. The curriculum emphasizes graphic sciences and technology within a quantitative management framework.

In 1965 the Graphic Arts Technical Foundation moved their research laboratories adjacent to the CMU campus. One of the stated goals of this move was to cooperate with local universities in the conduct of research activities.

Hence, with the combination of the long CMU involvement with the printing industry, the presence of the GATF laboratories and staff, and the launching of a major research effort into the science of robotics, it seems likely that significant robotics developments for application to the graphic arts industry would be forthcoming. The following examples of robotics applications to the graphic arts have been developed over the past twelve years. Some have been developed at the Robotics Institute, one pre-dates the Institute by over ten years, and the other was developed at Mellon Institute, CMU's contract research and development division.

1. Press Process Analysis. This project was started in 1966 as a joint investigation by GATF and CMU. One of the objectives was to develop a better control system for the press process. Initially, a single color lithographic press was studied, but the intent was to extend the analysis to multi-color presses of all processes.

The first stage of the project was to detail the nature of the interaction between the inputs to the printing process (including parameters such as paper smoothness and variables such as water feed) and the outputs of the printing process (print quality factors). There were 71 inputs and 41 outputs (Jorgensen and Lavi 1969) identified in this phase. The interactions between inputs and outputs were, for the most part, quite clear, but in a few cases the linkages were unclear. A handbook to aid the press operator in controlling the process was published in 1973 (Jorgensen and Lavi).

The next stage involved the computer modelling of the interaction between inputs and outputs. In order to make the task more feasible, only six inputs and nine outputs were used in the model. This selection included the more important outputs and the most frequently adjusted inputs.

The interactions were modelled by having experienced press operators compare the performance of the simulation with what they would expect on a real printing press (Doutriaux and Lavi 1974).

The most recent work on this project involved the generation of press sheets under a variety of printing control settings. The press control settings were recorded together with the corresponding measurements of the printed sheets, thus making feasible the accurate modelling of real interactions. To develop a complete model, it was first necessary to characterize both the dynamic and static responses. The dynamic response is the behavior of the process during the time required for print quality to stabilize between changes in operating conditions. The behavior of the process at the stable operating points characterizes the static response of the process. The modelling has been done by staff of the Electrical Engineering Department of CMU (Newman and Almendinger 1981). The combining of the static and dynamic models remains as the final phase of this part of the project.

It was decided early in the press process analysis study that the development of a true robot press would not be feasible. The problem centered around the lack of sensors for quickly and accurately evaluating the printed outputs. It was concluded that the human eye-brain system had to be incorporated as part of the control system in order to identify variations in print quality.

The potential robotics application of the press models concerns the adjustment of the press in order to reach and then stabilize print quality. The operator could input (possibly by voice control) the nature of the print defects and the press could then make the necessary adjustments to optimize the control settings.

2. Printed Circuit Inspection. Printed circuit inspection is a tedious and difficult task for humans. A considerable number of defective boards get by inspectors, and many good boards are flagged as defective. The Robotics Institute has recently developed a device (Thibadeau, 1981) for board inspection that is twice as fast as humans and twenty times more accurate.

This device can detect spurious copper, nicks, shorts, holes, breaks, underspec lines, and scratches. The inspection station consists of fairly standard optics, electronic camera, and computer hardware. A special purpose board handling device completes the station. The key to the system is the software, which allows a rule-based or computational solution to inspection. Hence, the approach is not simply pattern recognition, because there is no unique "good" pattern. Rather, the purpose is to have the computer comprehend bad patterns.

A "diagnostics engine" is also included in the inspection station. This program classifies the kind of defects, identifies their location, and correlates them with manufacturing inputs from such devices as chemical sensors. A causal model of the manufacturing process is incorporated into the computer so that, through comparison, the engine can provide judgements as to the causes of the defects. At present, the diagnosis is simply displayed on a graphics terminal. In future, a closed loop system that will allow the diagnostic information to direct improvements in the manufacturing system will certainly be feasible.

With appropriate adjustments, the printed circuit board inspection device could be adjusted to inspect special targets on conventional printed matter. For example, the center of a GATF Star Target could be examined to detect drift in the ink-water balance on a lithographic press. [Jorgensen (1981) has specified a visual method to determine correct balance.] A diagnostic device could then drive the appropriate ink or water controls, or signal the operator.

3. Press-to-Truck Automation. A major problem in the newspaper business involves the delivery of newspapers from the press to the delivery trucks. The papers must be in the right quantity, bundled in the correct numbers, and have the proper inserts and regional editions. Speed is very important also, because the trucks should not be kept waiting any longer than is necessary when they pull into a loading bay.

A robotized press-to-truck system has been developed by CMU's Mellon Institute (Hudak, et. al., 1981). This system,which is being installed and tested at a large Pittsburgh daily newspaper, can accommodate sixteen truck loading stations being fed by eight tying lines that run directly from the presses. The tying lines either can feed directly to the truck stations or to a continuous loop tray conveyor. The conveyor, which accommodates up to 35 bundles of newspapers, can function as a "holding" device until a truck pulls into a loading station. Each newspaper bundle has a "product" code which identifies the edition, advertising supplements, and other inserts. Ejectors push correct bundles off the conveyor trays as needed by a particular truck station.

Forty one microprocessors were installed, one at each control station (truck loaders, tray loaders, ejectors, and a tachometer). These microprocessors are connected to a PDP-11/34A host minicomputer that controls the operation of the system. As soon as a truck reports in at a given loading station, the system starts supplying correct bundles of newspapers, either from the tray conveyor or directly from the press tying line.

Press-to-truck automation represents considerable time savings for newspaper plants. The time value of other types of printed matter is rarely as great as that of newspapers, but it is possible for a smaller system to have applications within a plant for materials management and routing.

4. Production Management and Control. As production processes have become more automated, there has been a corresponding increase in specialized management personnel that are needed to coordinate, monitor, and plan production. In many factories white collar labor accounts for more than 50 percent of the cost of producing goods. A key element in the Robotics Institute "factory of the future" project is the Intelligent Systems Laboratory. An "intelligent management system" is being developed both to provide expert assistance in the accomplishment of professional and managerial tasks, and to integrate and coordinate the management of the organization (Fox, 1981).

In the future, most employees and all machines will have a computer terminal, each linked together. The system will first automatically acquire data on the status of plant activities. It will also represent the goals of the plant and then model the organization at many levels of abstraction. The system then either can provide expert assistance to humans for the accomplishment of complex tasks, or can manage directly plant activities. Plant management can be either passive, responding to user initiated queries on such matters as production scheduling. It also can be active, monitoring continually, the organization and informing responsible personnel when such important events as machine breakdowns occur. Finally, the system will be able to analyze how the structure and the processing of the organization should be changed to further optimize such criteria as cost, throughput or quality. More than ten years will probably elapse before a complete system is fully developed.

One subsystem that has been developed is an interactive, real-time, job-shop scheduling system. It can accommodate such scheduling constraints as cost, time, operations, and machines. The system uses a knowledge-based heuristic search to construct forward (from start date) or backward (from due date) planned schedules. The schedule is updated in real-time either by user input or by computer messages.

A printing plant is a classic example of a job-shop manufacturing plant. Such a job-shop scheduling system as has been described should have wide applicability to the printing industry.

Another interesting project in the Intelligent Systems Laboratory is the process diagnosis system. Its goal is to construct a system that monitors the production process, analyzes defects, and determines their causes.

Potential Robotics Applications in the Graphic Arts

Other applications of robotics to the graphic arts can be classified as "blue sky" thinking. However, such speculation cannot be called wishful thinking. With the continued decline of computer costs and the increase in programming skills, it is likely that some of the following suggestions will gain the attention of research and development personnel.

1. Press Makeready. Much press downtime is due to the makeready process, especially on four-color lithographic presses. An ideal robot makeready system would mount the plates, scan the images to determine and select the correct ink and water level settings, move the cylinders laterally and circumferentially to achieve correct register, and monitor and adjust impression pressure.

2. Plate Layout. Plate layout for packaging typically involves multiple images of several different designs or sizes. A laborious trial-and-error process is currently used to find a layout that satisfies production demands

while minimizing trim, layouts, and storage of excess products. The production of a robot step-and-repeat (or imposing) machine to solve the "gang" run problems of labels and brochures would seem to be a fairly simple matter. However, solving the "nesting" problem for cartons in addition to the other layout concerns would be considerably more complex.

3. Color Scanner Setup. Many color scanners have as many as 70 or 80 adjustment knobs. Because of the complexity of adjusting these knobs, most operators change only a few of them on a routine basis. Therefore, the setup of a scanner is not only time consuming, but it is rarely done in an optimal manner. A robot scanner would require as input a printed test form that would characterize the intended printing conditions, the output film characteristics, the original transparency or print, and instructions that identify the main interest areas of the illustration. Artificial intelligent techniques could then be used to optimize the setup and to adjust the scanner.

The Growth of Robotics Technology - Some Thoughts

According to all forecasts, explosive growth in the use of robots is expected over the next ten years. For example, General Motors had 1200 industrial robots in its plants by early 1982. One year earlier they had 300. By 1990 they expect to have 14,000 robots in operation. A similar growth rate is expected for Westinghouse - three years ago they had none, they have 90 in 1982, and expect to have several thousand by the end of the decade. For the robot industry as a whole, the forecasts of the annual growth rate range from 20 to 50 percent. Robotics will probably be a $3 billion per year business by 1990, with perhaps 200,000 units being sold annually.

The highest number of robots is, and will continue to be, in the metalworking industries. This is due to the large number of parts that need to be manufactured and assembled to form the typical product of the metal working industry. Printing, by contrast, involves little assembly, and in many cases uses in-line manufacturing techniques with raw material entering a machine and the finished product leaving it. Therefore, it is unlikely that the printing industry will use many of the robots common in the metalworking industry. The printing industry, however, will adopt artificial intelligence techniques in order to optimize current processes. AI could be utilized through stand-alone computer systems, or, more likely in the future, through robot presses, binding lines, scanners, or other conventional equipment. In other words, robotics technology is more likely to be applied to existing equipment and procedures in order to assist the operator to run them more effectively. Special purpose robots for materials handling tasks will be used by some printers, probably in the finishing processes, but their adoption rate will be fairly slow.

Because of the introduction of robotics, labor displacement could be a serious problem in some parts of the metalworking industry. By contrast, the impact of robotics on the printing labor market should be small because of the relatively slow-paced utilization of the technology.

Robotics technology promises to reduce costs and manufacturing times, improve quality, and lead to better management decisions. However, it will also mean greater capital investment with the attendant risks and opportunities of higher operating leverage. Given the demographic outlook for the future, we can expect a declining number of persons entering the labor force, especially entrants suitable for the highly skilled trades in the printing industry. This would suggest that the widespread use of robotics technology, especially artificial intelligence, is inevitable in the printing industry of the future.

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