INDUSTRIAL APPLICATIONS OF ARTIFICIAL INTELLIGENCE

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Abstract -- Artificial Intelligence (AI), is one of the key technologies that can be applied to bring the factory of the future closer to reality. Expert systems, in particular, can be used to solve problems in a number of areas that are only partially solved by traditional programming techniques. These areas include diagnostics, training, planning and scheduling, process monitoring, control and simulation.

AI has been used extensively within TI to improve manufacturing productivity and quality. Some examples of these internal applications, as well as external customer programs, are used to illustrate AI's potential for the factory of the future.

INTRODUCTION

The area of artificial intelligence that has received the most publicity in recent years is that of knowledge-based expert systems. A problem-solving technique, the expert system captures the knowledge of experts in specialized areas, or domains. Thus, it can provide expert levels of performance where human experts are either unavailable or not cost effective. Expert systems are tools, not replacements for human labor; an expert system can in many cases free personnel to extend their expertise to other areas. Also, key personnel sometimeS retire, transfer or quit; expert systems can smooth the transition and serve as a training tool for new personnel.

Expert systems derive their problem-solving power from a new approach to computer programming. There are many problems for which an efficient algorithm does not exist or the data required to solve the problem by an algorithmic method is missing or unobtainable. Instead of being programmed to follow step-by-step procedures, an expert system is programmed to follow a few general procedures for finding solutions to problems. Rules of thumb, models, facts and other knowledge about solving a problem (domain knowledge) are stored in the computer's memory. To solve a particular problem, the computer uses facts about the problem supplied by the user plus its domain knowledge and general problem-solving procedures to find and apply a particular solution.

Even though good progress has been made in expert system development "shells", most expert systems today still require the assistance of a trained specialist commonly known as a knowledge engineer. To construct an expert system, the knowledge engineer first interviews the process or domain expert to obtain the domain knowledge. Based on initial interviews, the knowledge engineer selects knowledge-representation schemes and reasoning strategies. Typically, development of an expert system is performed iteratively with a prototype built first and the knowledge base expanded and modified until the system reaches expert performance.

Expert systems will have a major impact in equipment and process diagnostics, in simulating and tuning processes, and in deciphering and reacting to alarms. They have the potential to change the way we conduct our maintenance and training and how manufacturing plans and schedules are made.

INDUSTRIAL AI APPLICATIONS: CASE STUDIES

AI technology has proven itself to be very powerful in helping to solve the problems associated with automating manufacturing processes. Described below are a number of areas in which AI techniques and concepts have been applied to solve problems and increase productivity both internally and for external customers.

DIAGNOSTIC EXPERT SYSTEMS

Expert systems have been used in a variety of successful industrial applications. The most frequent type of application has been in the diagnosis of equipment malfunctions. Routine maintenance and the diagnosis of relatively simple problems can usually be carried out in a fairly straightforward manner. But the diagnosis of really difficult problems or problems with very complex equipment often requires the guidance of an expert proficient in the equipment's design and operation.

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A well-known example of an diagnostic expert system is the system we developed for Campbell Soup to help diagnose malfunctions in large sterilizers used throughout Campbell's plants. In many ways the development of this system is typical of many of the others. These sterilizers are very large and complex. They stand 72 feet high and can hold up to 68,000 cans of soup at one time. The soup in the cans is raised to a temperature of 250 C using pressurized steam in order to kill off any remaining bacteria. Maintenance of these cookers is usually handled quite well by plant personnel, but, on occasion, problems arise that can only be solved by an expert who is very knowledgeable in their design and installation. Because of the amount of soup in one of these sterilizers at any given time, not to mention the backlog that can quickly build up, downtime can be very expensive. The objective of the system was to capture the knowledge of their expert, who was near retirement,and make it available to their plant maintenance people. Such a system would also free this expert to design new equipment. A rule-based expert system was developed on a personal computer using a development shell to troubleshoot Campbell's approximately 100 hydrostatic and rotary sterilizers. It also includes all of the start-up and shutdown procedures for these machines. The first prototype was constructed in one month and expanded and refined over another six month period. It has been installed in eight of their U.S. and Canadian plants and has been used successfully to diagnose problems. Similar expert systems have been developed to diagnose problems in the equipment that fills the cans with soup and those that then seal the cans. When problems arise with this equipment now, the operator simply inserts a floppy disk into the computer and follows the expert directions given.

The largest business entity at TI is its semiconductor manufacturing division. The manufacture of electronic chips entails the use of very expensive and complex equipment and reduction in downtime for this equipment is crucial. One such machine is an epitaxial reactor which uses high temperatures and carefully controlled mixtures of gases to help turn silicon wafers into working electronic circuits. The machine may process several wafers at a time and if improperly set up or a failure occurs while in process, thousands of dollars worth of scrap may be produced, while wasting many hours of reactor time. Because the reactors are so complex, only a handful of experts are skilled in diagnosing and repairing problems. Reactors could lie idle for several hours while waiting for an expert to arrive. To reduce that downtime, a panel of engineers created its own repair expert. Using an expert system shell on a portable computer, the team developed the Intelligent Machine Prognosticator consisting of multiple knowledge bases to diagnose equipment and process problems. The knowledge bases contain about 1000 rules to help the technician in diagnosing problems. Results from the system have been even greater than expected with mean time to repair decreasing 36%. Approximately 90% of the potential reactor problems are included in the expert system. Similar results have been obtained from other expert systems that are being used within Texas Instruments.

KNOWLEDGE-BASED PLANNING AND SIMULATION

Process planning expert systems can be used to optimize plant lay out and to simulate and diagnose processes. They can also be used as operator aids to assist production floor workers in the operation and set up of complex machinery. These systems can greatly increase the flexibility of both people usage and jobs by providing a constant level of expertise at key operator stations within a plant.

Corning Glass Works makes a number of products including color TV picture tubes for a number of manufacturers. These picture tubes are formed in a mold with necks and buttons for the electronics added in later steps. The tubes are then annealed to relieve the stresses built up in the glass. The annealing is performed in Lehr annealing furnaces typically 180 feet long and 10 feet high. The temperatures are controlled by gas burners near the front of the Lehr with a series of dampers, louvers and ports regulating the air flow to the rest of the furnace and letting cool air in. Set-up and tuning of the Lehr to achieve the desired annealing temperature, hold time, cooling rate and exit temperature is very difficult. When new requirements are received from manufacturers, Corning's expert in the design and installation of this equipment is often called in to set up the Lehrs. It is generally the case that the expert can successfully retune the process within two or three attempts. Corning wanted the project to focus on transferring the burden of assisting operators in adjusting Lehr firing and airflow systems from its human expert to a computer system. A secondary objective of the project was to develop in-house expertise so that AI techniques and procedures could be applied to other Corning processes.

After an initial interview with the expert associated with the annealing process, it was decided that the nature of his expertise was an ability to predict how various adjustments to the firing and airflow systems of the Lehr would affect temperatures at various points within the Lehr. A set of three knowledge-base systems was developed. The first system diagnoses the causes of glass breakage and identifies the process step and equipment at fault. The second system is a process simulator that allows an operator to make proposed control setting changes to the firing system and airflow adjustments and see the projected outcome of such changes on temperatures within the Lehr. This simulation was not based on physical principles of heat transfer and such, but instead on the expert's understanding (heuristics) of how those controls act on temperatures.

About halfway through the project it was decided to expand the range of the simulation expert system to include a planning component. While the simulator allows a user to try out control setting changes and see the effect on the annealing curve, the planner allows a user to input the desired curve and receive the necessary control settings. It acts as the Lehr expert by using an intelligent trial and error method to determine the Lehr control settings necessary to meet desired specifications of Lehr behavior. By iteratively telling the simulator what control setting changes to make, the planner can determine the validity of its "educated guesses", and adapt its strategy accordingly. All three systems were developed from scratch in the Lisp language and have been installed on Corning's computer in one of their plants for field testing.

SCHEDULING

Besides aiding in planning and simulation, knowledge-based systems are being devised to improve the efficiency of the manufacturing process itself. A key area where artificial intelligence techniques can improve manufacturing efficiency is scheduling. In multi-product, multi-line operations, scheduling becomes a difficult problem. Not only must customer due dates be met, but management is attempting to reduce inventories and minimize product cycle times. Achieving these multiple objectives in a complex environment is difficult with many of the scheduling tools that are available today. Several AI-based expert scheduling systems are being used within Texas Instruments. They are being used in environments as diverse as semiconductor manufacturing, machining operations and assembly processes.

In our machining operation, for example, an AI based scheduler is assisting with the development of production schedules including sequencing of production and dispatching of jobs to available machines. The AI system is composed of a planner, a scheduler and a dispatcher. The planner interacts with the production-control staff who enter monthly part needs. The planner formulates the monthly part needs plan into a daily pallet-release plan. The daily pallet-release plan is then passed onto the scheduler. The scheduler provides the production-control staff with the material requirements for the day and a list of tools to replace. The scheduler also maps out the sequence in which the jobs should be completed that day. This job sequence then goes to the dispatcher. The dispatcher monitors the state of the equipment through a real-time control computer system and, as machines become available, passes on the next action task for that machine. The AI system was developed and tested by using a second machine to simulate the machining operation. The system is currently installed and performing well.

ARTIFICIAL INTELLIGENCE: WHERE ARE WE HEADED?

From the examples given above, it should be clear that AI is having a significant impact in manufacturing and factory automation, but we've only just begun. The use of AI will continue to increase and will diffuse even more widely. As success stories increase so will the enthusiasm of more and more companies. Costs of both development and delivery systems will decrease rapidly in the years ahead as will the costs of expert system development. The key to the success of expert systems is the ability to embed them with conventional control systems so they become an integral part of the control system. An example is an online expert system developed for Calgon.

One of Calgon's businesses is the treatment of industrial cooling water. Industrial cooling water is critical to many industrial processes and its treatment is complex, often a mix of science and years of experience. Calgon's objectives were to develop an online monitoring and data collection system that would also assess the chemical state of the cooling water and recommend treatment. The approach taken by TI was to capture Calgon's many years of knowledge and experience in this area through knowledge engineering. The knowledge was then embedded in an expert system and integrated into the conventional control system using a programmable controller and a special I/O module capable of running a complex expert system.

A block diagram of the system is shown in Figure 1. The programmable controller reads the sensor inputs and controls the various actuators. The expert system resides in the I/O module and reads the input data directly from the controller's memory. The information is displayed to the user via various custom reports through a CRT or computer. The expert system also accepts off-line data through a keyboard or from another computer. All of the data is time-tagged and the age of the data is taken into account in diagnosing the state of the water. Historical data is maintained both for diagnosis and for uploading to other computers. The final system is quite large with over 1000 rules covering hundreds of diagnostic situations.

AI-BASED TRAINING AND MAINTENANCE

Another very important problem that AI-based approaches will help solve is that of training and maintenance. Industrial equipment is becoming more complex, is being used in more and more critical areas, and is becoming more reliable. Our traditional maintenance and training methods do not support these trends. Typically technicians are sent to schools to learn how to repair equipment. The increased reliability of the machines, however, means that by the time something breaks, the technician has probably forgotten how to fix it. The size and complexity of maintenance manuals only compounds the problem. A "Just-In-Time Training" concept has been developed that links expert diagnostic systems with laser videodisks and touch-screen monitors. Using the system allows the technician to be trained, as necessary, while a diagnostic expert system is guiding him to the equipment fault. When the fault is isolated he is trained on the spot to repair the equipment by having the appropriate training sequences invoked by the expert system. Such maintenance support systems will completely change the way in which we think about training and maintenance. A prototype of such a system has been built using an AT-compatible machine, a laser videodisk system and a touchscreen monitor. Future plans are to make the system much more portable.

CONCLUSION: AI AND THE FUTURE

As AI technology spreads into a variety of fields, one of the primary beneficiaries of this growth and maturing will be industrial automation. The benefits of applying AI will be seen in several key areas. It will help us preserve and distribute knowledge as in the Campbell Soup example. It will assist in reducing costs and risks with planners and simulators such as those developed for Corning Glass. It will help us increase throughput through the use of scheduling systems, such as the internal machining application. And it will help us diagnose and optimize our processes through the use of online experts, such as in the Calgon example.

In the pulp and paper industry in particular, AI has the potential to help optimize our processes, reduce costs and assist in the training of operators. Since the paper industry is capital intensive and uses specialized machinery, downtime can result in significant expense. Diagnostic expert systems can help the plant recover from equipment failures more quickly. The use of AI for online applications appears to have especially good promise due to the high level of automation and sensing systems that are in use. AI can be used to assist operators in the interpretation of alarms in recovery boiler or electrical systems. AI can also be used in conjunction with statistical quality control methods to analyze trends in paper variables such as weight, moisture and thickness. Recommendations can then be made on suggested adjustments to the process that are required. In the area of scheduling, AI can help develop production schedules that optimize plant throughput. Another potentially high payoff application for AI is to help optimize load shedding in power generation applications; AI based systems can be used to continuously monitor power loads and assist in minimizing the cost associated with a power generation loss.

Perhaps one of the areas with the most significant payoff is training. A system has been developed and is in use by Bowater-Carolina Corporation at its Catawba plant in South Carolina. The system is a simulator for a Recovery Boiler process and is used to train operators on proper procedures for avoiding unsafe smelt bed conditions. A well trained operator can help minimize the impact of recovery boiler failures, and thereby avoid significant plant damage or even human injury.

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CALGON
ON-LINE MONITORING AND DIAGNOSIS

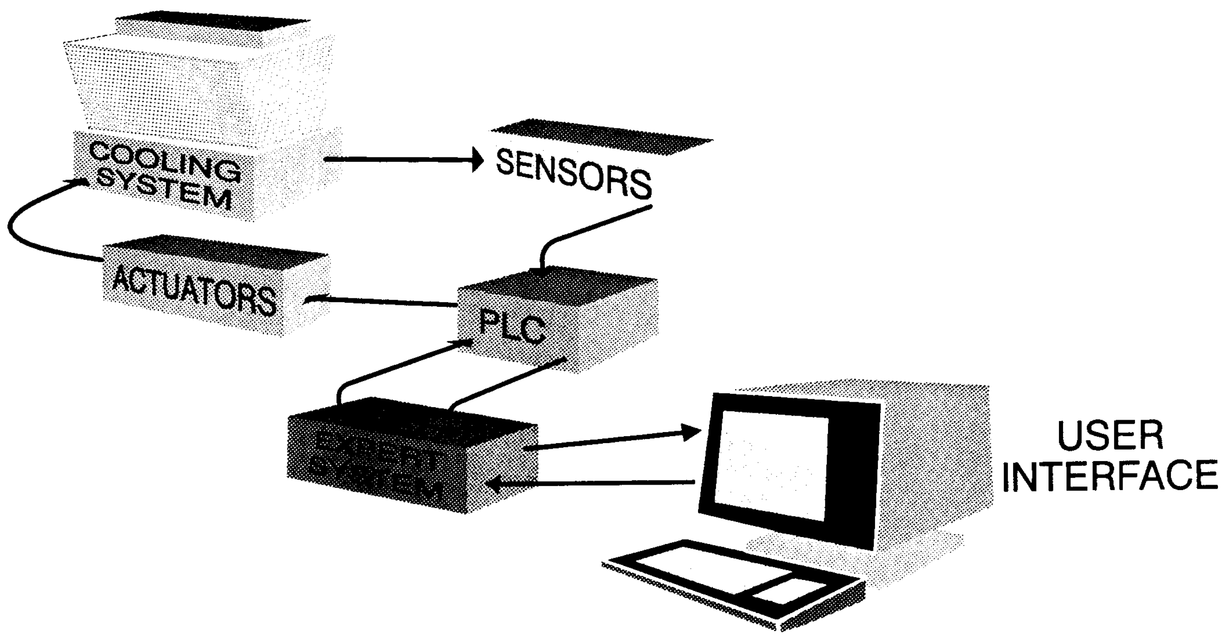

Figure 1: Block diagram of the Calgon online monitoring and diagnostic expert system.