THE POTENTIAL OF ARTIFICIAL INTELLIGENCE
IN SOUTH AFRICAN MANUFACTURING

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ABSTRACT:

This paper provides an introduction to the most commonly used Knowledge Based Systems (KBS's) called Rule Based Systems, presents some benefits of using these systems if the application warrants their attention and provides an over-view of current R & D as well as industrial systems already implemented. Areas of manufacturing that could use KBS's within the South African context are suggested. A research programme investigating the use of KBS's in robotics in progress at the University of Stellenbosch demonstrating a number of useful properties associated with programming Artificial Intelligence (AI) techniques using logic programming, is discussed.

1. INTRODUCTION:

Developments in the use of Artificial Intelligence (AI) for manufacturing attempted to emulate human cognition and expertise to make computers more useful in engineering. The high initial level of success triggered the creation of national projects in countries such as Japan (the Fifth Generation Computer programme), the United Kingdom (the Alvey programme) and in Europe (the Esprit programme). America principally has been active in investigating the applicability and practical use of AI throughout the manufacturing process. Despite the expected high feasibility of these efforts AI research has found limited implementation in industry. This is mainly due to constraints such as the massive investment of highly trained effort required and demand for very high computer speeds.

Currently the most popular and practical field of AI is Knowledge Based Systems (KBS) which includes a special subset termed Expert Systems (ES). The unique characteristic of KBS's is the knowledge base which provides a semantic representation of a particular domain. This is usually in the form of natural language sentences describing facts, events and the relationships existing between the facts and events. Decision making within the domain is based on heuristic reasoning as opposed to calculations with numbers. Expert Systems combine specialist knowledge with inferential procedures to solve problems in specific domains.

2. RULE BASED SYSTEMS:

The basic components of a KBS are a knowledge base, an inference engine and a user interface. The knowledge base contains information about a particular domain. The inference engine operates on the knowledge base to draw conclusions through some reasoning process and the user interface provides a link between the KBS and the outside world.

Rule based systems encode facts, events and relations as a set of
rules of the situation-action form. The general rule format is :

IF

        `<antecedent>` and

            "

            "

            "

        `<antecedent>`

THEN

        `<conclusion>`   `<confidence>` and

            "

            "

        `<conclusion>`   `<confidence>`

The antecedents are elements of a data structure that are matched
against entries in a data base and the conclusions result if the
antecedents match. The knowledge base is then a network of
interlinked assertions (rules) connecting initial input data
through numerous intermediate conclusions to the final conclu-
sions or goal.

The inference engine reasons with the rules using forward chain-
ing (data driven) and/or backward chaining (goal driven). For-
ward chaining is useful when a number of conclusions are possible
with little prior preference. The inference mechanism propagates
through the rule network by applying appropriate rules to the
input data and using the intermediate conclusions generated to
trigger other rules until a final conclusion is established.

Backward chaining is used when only a limited number of hypotheses
are to be considered. The inference engine starts by establishing
which conclusion goals are to be tested and then the relevant
rules are considered to see what evidence is needed. Rule selec-
tion propagates backwards through the knowledge base until all
the conditions needed to satisfy a conclusion are found or input
via the world interface.

3. THE NEED FOR KNOWLEDGE BASED SYSTEMS

KBS's have not provided efficient solutions for all problems. However, AI technology has enabled previously intractable problems to be solved. The reason for this lies in the differences between conventional and AI programming. The main differences between AI programming using Lisp or Prolog, and conventional programming using Basic or Pascal are :

- KBS's store knowledge using semantics and are structured according to human cognitive models. Conventional programmes use arrays of numbers and numeric sets of data which are not readily interpreted by humans.

- The knowledge base is separated from the reasoning mechanism (see fig. 1) allowing the systems knowledge to be changed without affecting the rest of the programme. A change to one line of a conventional programme could necessitate the restructuring of part or all of the programme.
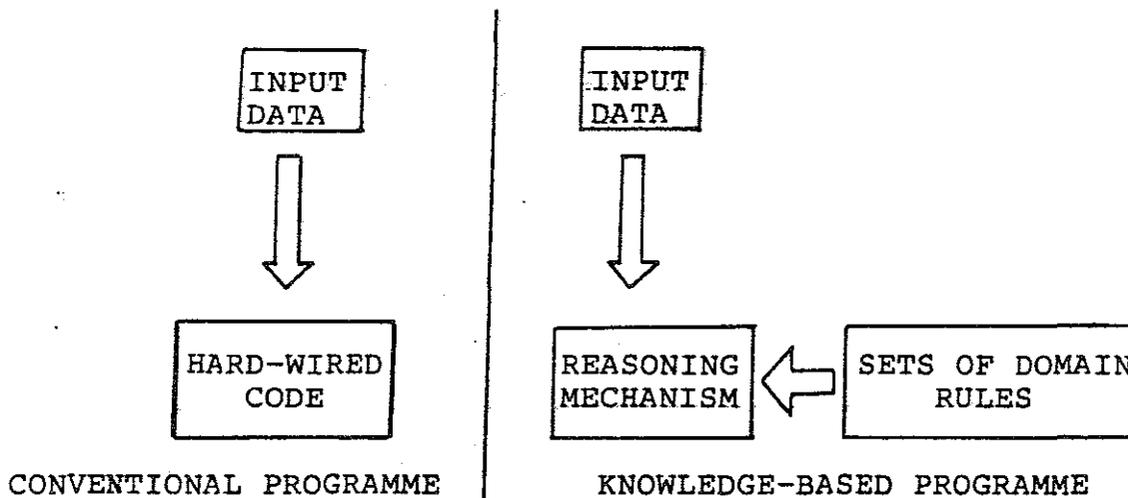

FIGURE 1 : STRUCTURES OF CONVENTIONAL AND
KNOWLEDGE BASED PROGRAMMES (Swift 1983)

- KBS's have the ability to explain why data is needed and how a particular conclusion was reached. Conventional programmes simply request data and give answers.

- KBS's can handle uncertainty or incomplete data both in the input data and in the knowledge base. This is more in line with human experts who make decisions with partial data. Conventional systems do not run if answers are not given when requested.

- Conventional programmes are strictly procedural. Activation of the next step is known in advance and programme execution follows a rigid sequence of instructions. KBS's encode knowledge in a declarative form and progress is determined by a set of rules which are easily adapted to new situations according to the evidence provided in a particular consultation.

- KBS's are programmed by providing information on what to do to solve a problem and not how to go about solving the problem as conventional programming requires. This is demonstrated in figure 2.

BASIC

```
10 INPUT X,Y,Z
20 IF X<Y AND X<Z THEN 60
30 IF Y<X AND Y<Z THEN 80
40 PRINT Z
50 GOTO 90
60 PRINT X
70 GOTO 90
80 PRINT Y
90 END
```

DBASE

NUMBERS(30,10,50)

RULES

```
IF      NUMBERS(X,Y,Z) AND
        X<Y AND X<Z
    THEN X IS LESSER OF X,Y,Z.
IF      NUMBERS(X,Y,Z) AND
        Y<X AND Y<Z
    THEN Y IS LESSER OF X,Y,Z
IF      NUMBERS(X,Y,Z) AND
        Z<X AND Z<Y
    THEN Z IS LESSER OF X,Y,Z
```

FIGURE 2 : CONVENTIONAL AND RULE BASED PROGRAMMES

There are other advantages to using KBS's that cannot be measured easily. The degree of benefit derived from the systems will depend on the quality of the knowledge represented. This is especially true of expert systems that attempt to function as well, if not better than a human expert. These advantages include :

- Expertise is available at the factory site when the expert is unavailable through illness, holidays or retirement.

- All the knowledge from different disciplines that are associated with a particular domain can be centralized.

- By distributing KBS's throughout the company, rare expertise is made readily available.

- Experts will not be disturbed to answer questions, thus allowing them to use their time more effectively.

- Expert systems can recall vast amounts of knowledge that human experts may not immediately be able to recall.

4. OVERVIEW OF EXPERT SYSTEMS IN MANUFACTURING:

A number of manufacturing process fields have their origins in AI research. This is especially true for vision and robotics. Both of these fields comprise machines with mechanical or electro-mechanical faculties i.e. the sensing device for the camera and the arm and motors of the robot, and of processing faculties i.e. the software needed to process images for the camera and to move the robots gripper in a straight line. The fields also include the design of software programmes for interpreting and controlling the devices. These manufacturing tools have been utilized in their present state. However, much work is still being done to improve their capabilities.

Knowledge Based Systems are being used in an attempt to enable the computer to understand an image and not merely record or manipulate an image. Knowledge about the domain will allow the computer to expect certain conditions which will aid the understanding process. Robot task programming is a higher level concept of robot instruction. Robots are told what to do to accomplish a task and not how to accomplish the task. If the robot has a description of its domain and has a knowledge base of how to perform standard tasks, much of the tedious programming required at present will not be needed.

Expert systems have been applied to a large extent in analysis and synthesis of manufacturing systems. Most of these ES's are implemented as aids that enable a human to perform a job more effectively. ES can be classified according to the function that they perform. The following ES's being used either in industry or research, have been grouped accordingly.

- <u>Diagnostic Systems</u> : Experience is an important factor in determining the speed with which a maintenance engineer can locate a fault in complex equipment. Expert systems can incorporate the knowledge of humans very experienced in maintenance and repair. This expertise can then be used by inexperienced people working at different places.

The General Electric Company developed a rule based system to assist mechanics in diagnosing and repairing Diesel Locomotive Engines (Miller 1984). After the user selects a particular problem area, the system prompts the user to answer questions and upon request gives the reasons for the questions. Once the fault has been identified the ES advises how to repair the fault also in the form of training video sequences displayed on a video monitor.

A number of smaller ES's are used to aid humans find faults in electronic equipment, motor cars and computers. The applications for this type of ES are limitless and more of these systems are likely to be seen especially due to the increase in the number of ES shells currently available for the personal computers.

- <u>Planning Systems</u> : Optimum solutions to problems are found by these systems. Rules are used to encode the knowledge of the problem domain and heuristics (rules of thumb) drive the rule selection process. The most successful path through the knowledge base forms the plan of action to achieve the desired result.

The best known ES to be implemented in manufacturing is XCON used by Digital Equipment Corporation. The programme configures VAX 11/780 and other computers starting with the order and ending with a number of diagrams for the computer system. Programme

performance is better than any expert as the computer can recall vast amounts of knowledge and consider all options during the planning process.

At the University of Maryland, Nau (1982) investigated the use of an ES for process planning. The system plans a sequence of machining operations to perform a job at least cost and specifies the type and size of machine tools to be used.

A research programme developed by Taylor (1986) determines the welding process and edge preparation specifications needed to weld materials of various dimensions and properties. The ES structure allows easy amendments to the knowledge base if a new welding process becomes available and a new edge preparation is needed.

Long term research programmes at the Carnegie-Mellon University include the development of an Intelligent Management System (IMS) that aids managers in their day to day tasks (Fox 1982). The ES answers questions such as :

- what if the grinder goes down with maintenance problems ?
- how do I select a process to be used ?

Also under development is a Knowledge Based Simulation system (KBS) that has facilities for the interactive creation, alteration, monitoring and control of job shops (Reddy & Fox 1982).

- Design Systems : ES can advise designers and check finished designs to aid humans in producing optimum products that can be realistically manufactured. These systems need to consider all types of manufacturing processes appropriate for producing a part and eliminate the need to return a drawing to the designer if e.g. the process planner finds the part impossible to produce. ES's of this nature are usually implemented at the CAD (Computer Aided Drawing/Design) work-station and use knowledge of manufacturing processes to iron out production problems at the design stage.

Markus, Markusz, Farkas & Filemon (1984) describes an ES that prepares milling machine work-piece fixtures by building clamps and supports, from a kit of elements, to hold a specified object. The ES forms part of a design system that would advise a human as to the feasibility of the design.

Research at the University of Hull is directed at knowledge based consultation systems that will help engineers design for economic manufacture. Swift (1983) describes an ES that makes decisions as to what materials and coatings to use to fulfill a specified surface finish and strength requirement.

- Control Systems :   The advances in sensor and computer technology have paved the way for automated manufacture. If the manufacturing system fails or reaches potentially dangerous conditions human operators are inundated with alarms and upset indicators which need to be interpreted immediately. An ES containing relevant knowledge can diagnose the problem and implement or suggest appropriate error correcting procedures.

Young (1985) developed a knowledge based control system to schedule and dispatch operations in a flexible manufacturing system. Meta-control of the system involved the use of two models. One model planned and predicted the impact of decisions and a second model implemented the approved decisions. This has advantages over manually operated systems.

The Japanese success with their manufacturing techniques made western industry increasingly aware of the cost of producing and storing mass produced products. As a result there has been a shift towards developing flexible manufacturing systems that manufacture a greater variety of parts in smaller batches. To fully utilize FMS's it becomes necessary to programme machines off-line and to minimize machine change-over time between production runs. Large amounts of sensor based data must be obtained for quality control, material handling, failure detection and production monitoring.

5. APPLICATIONS IN SOUTH AFRICAN MANUFACTURING:

Reinecke (1985) suggested that ES's could be used to support unskilled labour in skilled jobs. The world interface could utilize standard switches, warning lights and other displays to direct the labourer as required. Through the appropriate utilization of man and machine, each could compliment each other i.e. the human providing the dexterity and visual capabilities (things that humans are good at) and the machine providing the reasoning capabilities by accessing large amounts of data and heuristic knowledge at a rapid rate (things which machines are good at).

The immediate possibilities for the integration of man and computer in South Africa are in maintenance and fault diagnoses of specific equipment. This is especially applicable to the electronics industry where the repair of a electric circuit requires dexterity and the fault finding procedure requires expertise.

Flexible Manufacturing Systems require less skilled labour than conventional manufacturing for their real-time operation. However, highly skilled labour is needed for its implementation, maintenance and programming. It is socially important, especially in South Africa, not to utilize FMS's purely as an economic replacement of human labour. Knowledge based systems could provide a mechanism by which unskilled labour could be supported so as to perform the system maintenance and monitoring. By a suitable use of expertize on the shop floor and a functional computer interface, unskilled labour could be guided in system control.

ES's for planning and design are seen as tools to be used by skilled humans and although their use would improve the total manufacturing efficiency, South Africas' immediate need is seen to be the support of unskilled labour.

6. RESEARCH AT THE UNIVERSITY OF STELLENBOSCH:

Research at the Center for Robotics (SENROB) has been concerned with FMS control using AI techniques and languages. This is a first step to integrating KBS's with manufacturing processes.

Greef & Reinecke (1987) demonstrated the use of a KBS for robot supervision in a FMS cell. The robot is programmed to respond to messages sent from interacting machines and a camera. Advantages of using a KBS include rapid programme development and alteration e.g. if another machine is added to the FMS cell the supervisors knowledge base could be updated without affecting the rest of the programme.

A knowledge based FMS consisting of a PUMA industrial robot, a CNC milling machine, a CNC lathe, a pneumatic chuck and a Micro-eye CCD matrix camera was built (see fig 3). A Local Area Network connects the machine controllers which are IBM compatible computers. The network is a peer system and all devices can communicate directly with each other. The mill and lathe controllers execute standard "G" & "M" code programmes. The PUMA controller executes VAL I programmes and the camera image processing software is written in assembly language. Prolog, a logic based AI language, is used to programme the robot supervisor.
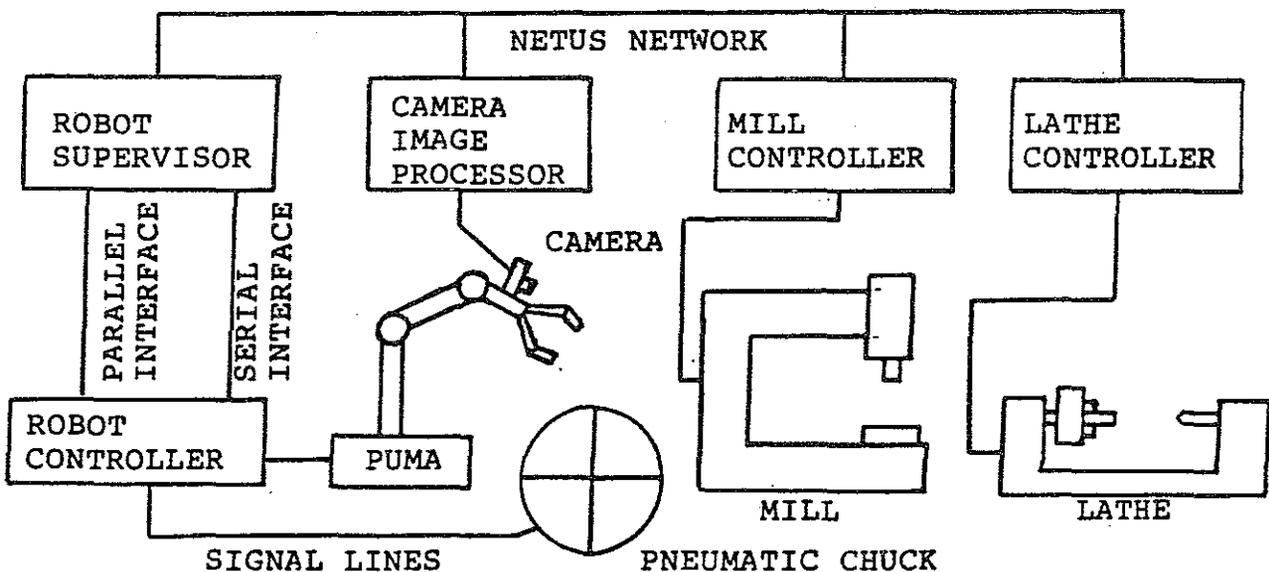

FIGURE 3:   THE KNOWLEDGE BASED FMS LAYOUT

In the demonstration of the FMS, the robot performs two tasks. One task requires the robot to continuously use the camera to detect the presence of a palletized metal pin. If a pin is detected it is loaded into the pneumatic chuck where it waits for 5 seconds before being moved to an out pallet. If no pin is detected then the robot would consider the next position in the pallet. The second task is to load and unload the mill and lathe when the devices finishes their machining programmes and transmits a message requesting service.

A data base contains the status of the system as a set of facts indicating states such as which gripper the robot is holding and which robot programme is currently executing. The KBS continuously attempts to invoke the separate expert systems responding to input from the PUMA robot, the network, the keyboard and a change in robot state. Once a particular ES is triggered a forward chaining propagation through the knowledge base results as the antecedents of the rules are matched to facts in the data base. The rule conclusions produce side effects which instructs the robot to execute a particular programme or which transmits a message to a device or which invokes another rule.

Advantages of using a KBS structure and AI programming include :

- ease of system status representation using natural language.

- rapid system development and adjustment in modular programme segments.

At present the KBS is implemented at the machine communication level. Future development with the system will include enhancing the man/machine interface to enable unskilled people to operate and maintain the FMS.

7. CONCLUSIONS:

Artificial Intelligence has gained world wide acceptance as a useful tool for manufacturing. The areas where AI can be applied are unlimited and there are many benefits resulting from capturing human expertize for distribution throughout the factory. Many ES's are still in the research phase. There are however a number of ES shells that can be used to implement ES's in industry. These shells are mainly rule based systems that incorporate forward and/or backward chaining reasoning mechanisms.

The benefits of using KBS's have been given here and some interesting applications of ES's in manufacturing were mentioned. KBS's can be classified according to their function of which maintenance and control are the most appropriate areas for research in South Africa. These two application areas can be used to support unskilled labour in performing skilled jobs.

Research at the University of Stellenbosch is concerned with the use of AI techniques to support unskilled labour in the operation and control of FMS's capable of "lot size one" production. A demonstration of such a FMS cell has been developed that incorporates KBS methods to supervise a robot in performing material handling tasks.

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