Proceedings of the 7th British Robot Association Annual Conference

Edited by: T.E. Brock

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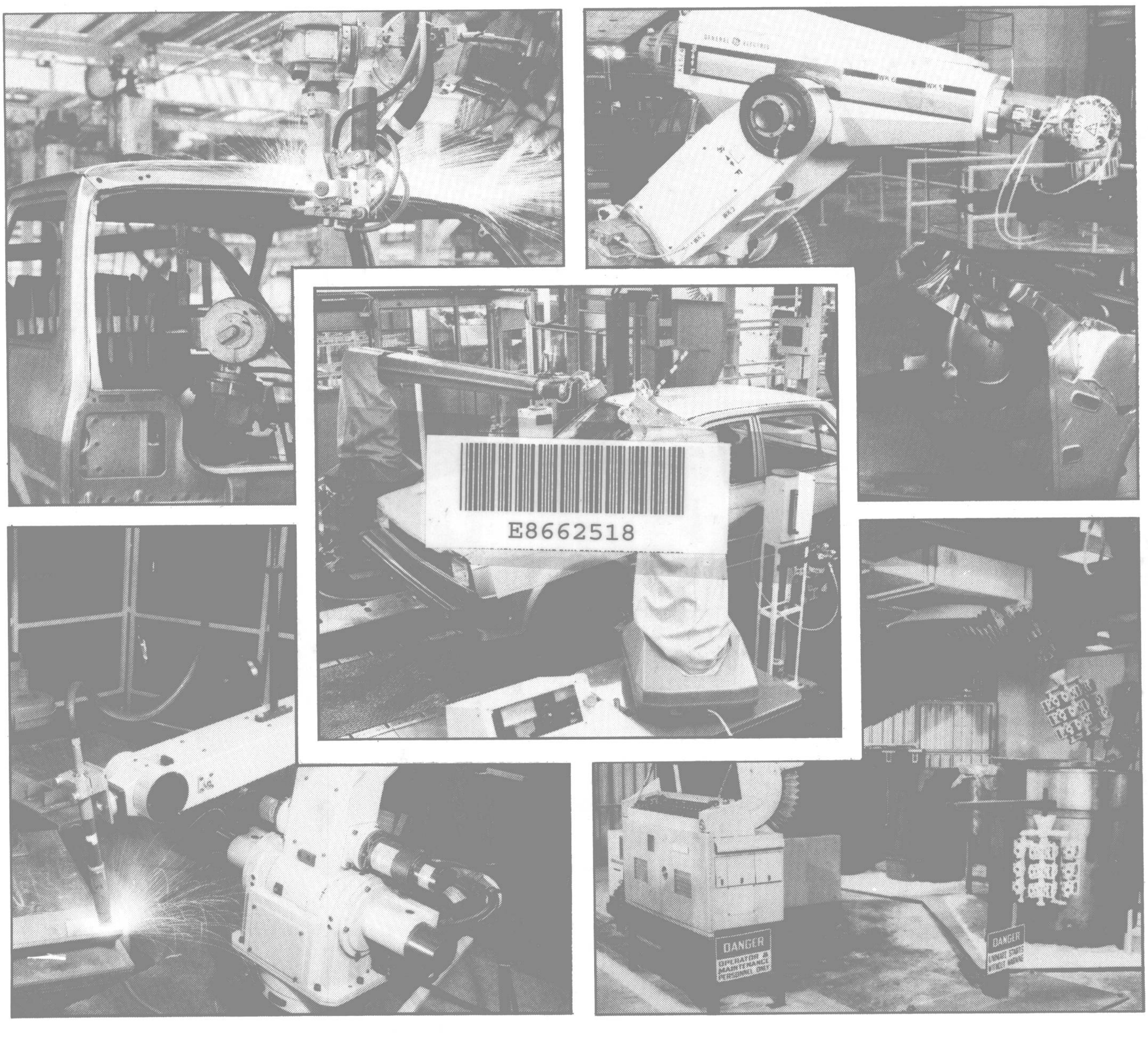

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Government Support for Advanced Manufacturing Technology

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Advanced Manufacturing Technology (AMT) offers substantial benefits to manufacturing companies but is not being adopted as quickly as it might be. The main constraints are lack of awareness, high risk, shortage of skilled manpower. The paper reviews the Department of Trade and Industry's programmes for encouraging the development and wider use of AMT (robotics, CADCAM, flexible manufacturing systems, computer-aided production management) including awareness, consultancy, demonstration, financial assistance for R&D and installations. It deals with the position in March 1984; further details of future plans will be given at the Conference and literature giving up-to-date information on the programmes will be available.

The Department of Trade and Industry's Advanced Manufacturing Technology (AMT) campaign is aimed at ensuring that all manufacturing companies

are aware of the potential of AMT for improving competitiveness

make a full assessment of their current manufacturing activities

invest in AMT on the appropriate scale to reap the benefits.

This is the first priority. But we also want to see a strong UK based supply industry so that users have easy access to the most up-to-date techniques and are concerned to identify and help to reduce major constraints such as a lack of skilled manpower.

Initially the campaign focussed on specific manufacturing technologies of which the Robot Support Scheme launched in 1981 was the first.

Under this scheme, we have funded 116 studies of the feasibility of using robots in manufacturing applications and offered assistance of £3.5m towards 36 R&D projects involving the development of robotic devices and £14.9m towards 187 projects involving the application of 310 robots in a wide range of companies - a total commitment of £18.6m. Welding (40) is by far the largest application area with assembly (16), handling (14) and paint spraying (12) next. Some 30% of applications are from companies employing less than 200 but given that robotics offers a particularly appropriate route for small firms to start on the road to AMT, we would like to see many more. We would also want to see more innovative applications from the larger companies for example more complex assembly projects.

Now that the scheme has been running for some time, we are beginning to see projects coming to fruition and we shall be picking out case studies to illustrate the benefits to other potential users. I do not need to tell this audience that these can be substantial for example one small firm hopes to cut manufacturing time from 40 to 12 minutes per item and another by 63 to 12 minutes: while a medium sized company is introducing a robot for chemical spraying to reduce spray time by $\frac{3}{4}$, remove workers from a hazardous and unpleasant working environment and improve the consistency of the spray finish.

The Robot Scheme was followed by the CADCAM Awareness Programme (subsequently extended to embrace CAPM - Computer Aided Production Management) and by the Flexible Manufacturing Systems (FMS) Scheme.

To date over 3,400 firms have made use of the facilities offered under the CADCAM awareness programme - management seminars, practical experience centres and demonstrations of systems in operation in companies. Some 800 companies have undertaken studies in the feasibility of adopting CADCAM at a cost of £2.01m while over the last 18 months we have received 1,100 applications for assistance towards the purchase of CADCAM hardware and software. This represents an investment of £112m by first time users of which one third were small firms.

Last year the CADCAM programme was broadened to offer assistance for computer aided production management (CAPM) which includes grants for assistance towards the cost of planning studies with the aim of encouraging strategic planning. This type of assistance also features in the Flexible Manufacturing Systems (FMS) Scheme and the aim is to encourage strategic planning before investing. It does not make sense to agonise over the return on investment on the purchase of a robot costing £20,000 because the firm down the road has one when you have hundreds of thousands of pounds of unnecessary "work in progress" lying around your factory. This assistance for planning studies is complemented by grants of up to a third of the costs of installing an FMS. To date 57 companies have received assistance of £1.09m for FMS planning studies and 24 offered assistance totalling £12.7m towards installation projects. Not all of these are large; 9 of the companies have under 500 employees (5 of which have under 200).

The FMS scheme is selective. Through it we are seeking to support a representative range of projects in a wide range of sectors of industry to demonstrate the benefits. One of the major problems is that AMT is often difficult to justify against standard return on investment criteria, particularly improvements in quality, reduction of waste and generation of new business. But once installed the benefits can be substantial. Normalair Garrett has had an FMS operating since 1982. Output per employee has trebled, unit costs reduced by 20%, stock and work in progress turnover reduced sevenfold and lead times on orders reduced from 17 to 2 weeks. In the CAPM field, Beaver Machine Tools, a company with 200 employees, invested £50,000 in a production control system to control 10,000 piece parts which reduced work in progress by £300,000 in just 12 months.

This is the history of support in the AMT to date. But as the ACARD report 'New Opportunities in Manufacturing' points out

> "The technologies associated with manufacturing ...... have reached the stage of development where system integration is becoming feasible, drawing the design, production, marketing, commercial and financial functions together and thus allowing the concepts of the integrated engineering systems and the automated factory to become a reality."

This is not to say that every company should move to full automation overnight. A step by step approach is sensible for the majority and particularly appropriate for small companies for whom the purchase of their first robot system can be a significant step forward. Each step must be compatible with the next and the whole process should start with a thorough review of the company's activities through feasibility and planning studies to draw up plans. For these reasons the emphasis in the Department's campaign is now on the need for a company to draw up long term objectives for integrating its manufacturing activities, seeing the introduction of individual activities and steps on the road to integration. Assistance for feasibility and planning studies has a key role to play here in helping a company establish the right framework.

Automated manufacturing also puts new demands on people with new requirements for education, training and retraining. Firms will be looking for technicians and engineers who can take a systems approach to manufacturing problems and have an electronics and computer software dimension in addition to traditional engineering skills. There is a growing need for people with dual engineering and computing skills to enable firms to develop their own customised integrated engineering and business systems from those software modules that are available in the market. There are several appropriately integrated courses in some of the universities and polytechnics, but there are, so far, not enough. Government is urgently addressing this question. We need industry to help by specifically identifying what skills they will require.

A major difficulty with mid-career training is that of releasing middle management for short training courses. The development of the distance learning techniques and preparation of material for use in-house by management and training staff is one solution. With this in mind, the Department has put its management seminar and case study material into a kit form for in-firm use. We have also commissioned several video tapes. We are also working closely with Open Tech who are developing distance learning material on the technologies themselves.

The Training Company Scheme, which the Department runs jointly with the Science and Engineering Research Council is one successful means for introducing Advanced Manufacturing Technology into industry. It has brought some of the best engineering graduates into manufacturing companies. It is by no means restricted to young engineers: graduates from all branches of science and technology are contributing to this solution of real industrial problems. Over 200 graduates have taken part in the scheme, of which over one half were subsequently employed by their company. And most of the others stayed in manufacturing industry. A further 230 graduates are currently in post.

It has improved the industrial relevance of university and polytechnic teaching. It has helped close the gap between industry and the higher educational sector.

To sum up the Government attaches importance to encouraging the use of AMT throughout manufacturing industry to maintain the UK's place as a major manufacturing nation. Much has been achieved so far but there is still a long way to go. Government can help to create the right climate and offer practical assistance but the main commitment must come from companies themselves.

Reference

1. Advisory Council for Applied Research & Development. New Opportunities in Manufacturing: the Management of Technology. HMSO London October 1983 - Page 15.

ROBOTICS IN THE USA - A PERSONAL VIEW

THE 1983 BRA TRAVEL SCHOLARSHIP

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The 1983 Tour embraced visits to 14 US Robotics Centres. These included the Universities of Purdue, Rhode Island, MIT, and Carnegie Mellon; robot manufacturing organisations such as Unimation (Danbury), Cincinnati Milacron, GMF and Control Automation; and industrial users including GE, General Motors, Chesebrough Ponds, Doehler Jarvis and Ford. This paper describes some of the research areas which are currently important and the ways in which this research is funded. It describes the successful emergence of industrial "in-house" automation groups and focusses on current themes in US robot manufacturing and marketing. The paper concludes with a consideration of the implications for robotics in the UK.

US UNIVERSITY RESEARCH

There are three major themes characterising current research:

a) Large-scale funding and strong industrial involvement.
b) The intelligent robot.
c) Computer Integrated Manufacture.

Funding

Funding for robotics research derives from the Government (National Science Foundation), Defense contracts and industry. MIT dedicates $3 million a year to robotics work in its A.I. Lab and is in the fortunate position of being able to turn away this amount again from potentially willing sponsors who might not prove quite so reliable in the long term as some of the established sources. A major proportion of the $3 million is provided by the Navy and is relatively non-specific allowing work to proceed on long-term research. The financing of the Carnegie Mellon Robotics Institute is an impressive example of the commitment that US industry has to the future of automation. 70% of the Institute's annual budget of $8 million comes directly from industry. DEC, Westinghouse, IBM, Xerox and Bechtel are some of the major sponsors and altogether 150 staff are involved in an extremely broad-ranging research programme (see Williams [1]). The Institute is thriving on simultaneous industrial collaborations and this characterises other robotics research programmes; e.g. at URI (with a current budget of $1 million) an industrial advisory council and an industrial participation programme are key features in the structure of the Robotics Group. (see Fig. 1). At Purdue a strong industrial involvement (particularly in the area of Computer Integrated Manufacture) is paralleled by extensive funding from the NSF.

The Intelligent Robot

One view of the possible capabilities an intelligent robot of the future might have was recently provided by one of the pioneers of world robotics, Professor Lou Paul of Purdue.[2] "The intelligent robot of the future will have two arms, provide for force and motion control, incorporate vision, tactile sensing and new programming systems and will cost less than the magical $100,000 ". These capabilities will exist in a hierarchy in future robot controllers (see Fig. 2). At the base of the hierarchy is servo control of motion and force.

Motion and Force Servo Control The aim of motion control is to drive the degrees of freedom of a robot in such a way as to minimise trajectory tracking error and to ensure the smallest possible error in static positioning between desired and achieved joint displacements. This together with trajectory planning is a well-documented (see Vukubratovič [3] and Coiffet[4]), and reseached area, although progress is still being made. Robot dynamics have to be taken into account if successful motion control is to be achieved at high speed. This is either done implicitly during the design of the servo control system or explicitly in an on-line dynamic control approach. The latter is favoured by Prof. John Hollerbach of MIT. In the past, one objection to this approach has been computational expense but this might not be so in the future as one of Hollerbach's colleagues recently developed a VLSI dynamics chip in collaboration with Hewlett-Packard.

Several of the landmarks in the area of robotic control have been generated at Purdue by Prof. Paul and his colleagues during the last 5 years in a programme backed by the NSF. These include "resolved acceleration control", "minimum travelling time control", and "resolved force control".

If the scope of robot applications is to broaden then a robot must be capable of physical interaction with its environment. This interaction embraces manipulation, sensory interaction and the exertion of controlled forces. Force control is a relatively young subject and there are many associated problems to be overcome. Small, yet robust force and torque transducers must be developed. One major problem is modelling and understanding interactions with objects in terms of contact forces; some progress in this area has been made at MIT by Prof. Tomas Lozano-Perez. Another expert on force control at MIT is Dr. Ken Salisbury [5] (formerly of Stanford). He has developed a 3-digit hand, capable of stable grasping and limited reorientation, and driven by tendons. Theoretically he has explored the mathematics of grasping and stiffness control. Raibert and Craig [6] have also made progress in the area of force control by developing a hybrid position and force control system. Despite all these developments considerable progress still has to be made if robots are to have full force control capabilities.

Vision A view that was reiterated throughout the tour was that there was a need to establish more fully the science of robot vision. It was stressed that existing industrial applications of vision rely largely on fairly ad-hoc techniques and that the future lay with advanced 3D, possibly "model-based" vision systems. Dr. Mike Brady of MIT is a strong advocate of advanced vision systems. John Canny, one of Brady's students, recently published his Master's Thesis [7] on "Finding Edges and Lines in Images". He notes that edge detection is the basic first stage in many vision algorithms. Canny's contribution has been to recognise that one can measure "performance" by specifying criteria capturing the requirements of a good edge-detecting operator. From these criteria, he derives mathematically optimal operators. The criteria chosen are:

a) Low probability of error, i.e. failing to mark edges or falsely marking non-edges.
b) Marked points should be as close as possible to the true edge.
3) Low probability of more than one response to a single edge.

An example of the performance of one of the optimal operators derived by Canny is shown in Fig. 3.

It was at MIT that a great deal of stereo vision theory was derived and some of the algorithms developed include: "shape from shading", "shape from motion", "shape from contour", "shape from texturing", and "photometric stereo". (In the latter approach multiple images of the same scene are taken from the same position with different illuminations and the surface orientation is determined from the brightness values at each point.)

At CMU Prof. Gerry Agin is working on 3D shape analysis and understanding. Dr. Jim Crowley has developed a technique based on the DOLP (Difference Of Low Pass) transform which is useful for 3D object description and is highly computationally efficient.

The URI approach to vision is based on techniques which generally are more heuristic than some of the fundamental algorithms researched at MIT; nevertheless they are highly advanced and effective. Several successful algorithms were developed here in the solution of the "bin-picking" problem and this is still a major research theme. The emphasis is on algorithms which are reliable and may be implemented using today's computer hardware. Both GE and Object Recognition Systems of Princeton have developed successful commercial "bin-picking" systems based on the work at URI.

Tactile Sensing A good review of the state of the art in tactile sensing is given by Harmon [8]. Work is progressing in the area of trying to identify and locate objects using data from multiple tactile sensors (see Lozano-Perez [9]). An exciting development in this area is that of a VLSI tactile sensor by Prof. Marc Raibert [10]. A prototype has been constucted incorporating 6x3 1mm tactile cells, each of which is equipped with its own computing element. The future should see large tactile sensing arrays capable of rapidly processing information derived from manipulator interaction with its environment and this will be of great importance in providing useful real-time information for control.

Artificial Intelligence and Advanced Programming Several of the vision systems already mentioned, incorporate great intelligence. A.I. will also be required to enable a robot to be programmed in a high level language (task programming). This is the objective of Edinburgh's RAPT project and related work is being undertaken at MIT by Prof. Lozano-Perez and colleagues. The intelligent robot of the future will have a highly sophisticated central intelligence capable of monitoring and interpreting sensors and sensor processors, of decision making and scheduling, and of precise motion and force control in response to programming by humans or a computer. Work is required not only on particular features but also on coordination of the whole system.

Recent work at Purdue by Hayward and Paul [11] on "Robot Manipulator Control under Unix" represents a concerted effort in the direction of an intelligent system. An extremely flexible controller for the Puma has been developed in the "C" language and running under the Unix operating system. It provides for motion control, force control and sensory integration and is currently being further developed.

Considering again the features an intelligent robot might have, not much work has been done on two-armed robots. Prof. Luh however has tackled a closely related problem, namely "the coordination of two industrial robots" [12].

Computer Integrated Manufacture

CMU is expending a considerable effort in flexible manufacturing research, particularly in the role that expert systems will play. Prof. David Bourne is developing natural languages for robot communication in flexible manufacturing systems. Another recent development has been that of the ISIS system which is an AI based "Production Management and Control System". ISIS provides real-time reactive plant scheduling. It optimises schedules by utilising and "relaxing" constraints in the scheduling process. Categories of constraints include:

a) organisation goals (dates, cost and quality)
b) preferences
c) enabling states (resources, previous operations)
d) physical characteristics (accuracy and size)
e) availabilty

An expert system for printed circuit board inspection and defect diagnosis has also been developed. Course and fine analysis techniques have been applied to enable rapid flagging of faults and defect analysis. This has applications in other inspection tasks aswell as in robot vision.

There are several Universities in the USA with large research programmes in Computer Integrated Manufacture and without doubt one of the most ambitious of these is the CIDMAC Project (Computer Integrated Design, Manufacturing and Automation Centre) at Purdue University. This first began in July 1982 after a year of planning and fund raising. 80 researchers and graduate staff are involved in this broad-ranging project which is tackling all aspects of FMS including: computer-aided design, databases and communications networks, the human interface to FMS, sensing (including voice I/O, vision, inspection and depth perception), software tools for planning the design and operation of manufacturing systems, and finally instrumentation and robotics. A focal point for the whole project is a totally integrated FMS for rotational components which gives great relevance and direction to the research. Once again expert systems have a key role to play, especially in the area of software tools; many of the implementations utilise Prolog. Fig. 4 illustrates the structure of an expert system for facility planning incorporating a database management system.

CIDMAC is strongly supported by US industry. Indeed, it was set up largely as a result of prompting by industry to institute a total systems initiative on flexible manufacturing. Key elements in the success of the project are the on-site company representatives. Experience has shown that day to day interaction has been invaluable. We can certainly expect to hear more of the CIDMAC project in the future.

INDUSTRIAL RESEARCH AND DEVELOPMENT

US industry is responding to the challenge of industrial automation not only through strong collaboration with Universities but also in a strong in-house effort.

General Motors

GM has been at the forefront of robot technology for over a decade and has made several significant breakthroughs. Since "Consight" and "Keysight" over 100 different vision and inspection systems have been installed. Recent applications include visually assisted engine valve insertion, RCC assisted assembly, rack stacking of painted bonnets and laser inspection of parts. The latter application is still being researched and is linked to GM's extensive CAD modelling facilities. GM has initiated an advanced manufacturing programme in which CAD, Body Modelling and Off-line Programming will eventually be linked to set up advanced manufacturing facilities of the future. There are large research groups tackling the problems of advanced model-based vision systems and advanced software tools and these work closely with the Groups responsible for actual robot installation and applications development (Advanced Product and Manufacturing Engineering Staff - APMES - see Fig. 5). A recent success has been the full commissioning of the GM NC Painter robot, now marketed by GMF. Painting is probably one of the most important robot applications in the automotive industry and the NC painter has shown itself to be a considerable advance over existing systems.

GE

GE markets foreign robots under license and will soon be selling robots and controllers of its own design. In addition it is involved in some exciting applications work of which the TIG welding system "WELD-Vision" is probably the most famous. This is a multi-processing single-pass system for TIG weld seam following, in which weld parameters are monitored on-line (e.g. weld puddle size, geometry of the joint) and compared with an open-loop model of the welding process to generate corrective software compensation. The system has recently come onto the market and future developments will be the incorporation of a 3D vision system based on "Optical Flow" techniques to enable more accurate puddle monitoring. GE has also researched an adaptive spot welding system and is actively engaged in research into CAD programming systems.

Ford (Batavia)

At "1981 Front Wheel Drive" over 40 robots have been retro-fitted into a modern plant occupying an area of 259 acres and responsible for the production of 550,000 automatic transaxles (ATX) per year. Robots have been utilised in what was previously the domain of dedicated automation in order to give flexibility to the manufacturing process aswell as to improve quality control. Machine tool loading and unloading form the bulk of the applications and extensive use is made of "double-dual" grippers. In most applications robots are responsible for not only handling parts but also for orienting them for further automatic assembly. For high tolerance operations the robot is programmed to send a part down a gauging chute at a pre-determined frequency for checking and this has improved quality control. There are slight differences in the assembly process for different models of transaxle and robots at key points in the process give sufficient flexibility to cope with different batches.

Much of the systems engineering work for the new robot applications has been done by local systems houses under the direction of Ford production engineers. Among novel applications are:

a) Use of a Cincinnati T^3 (hydraulic) to 1) track a monorail conveyor, 2) unscrew a carrier clamp and 3) unload the almost complete ATX assembly from the conveyor and onto an indexed conveyor pallet.

b) Use of 3 deVilbiss Trallfas to dechip "worm trails" and holes using high pressure liquid.

Chesebrough Ponds

Ponds has many products in the make-up, food, clothes and hospital supplies markets and has an annual turnover in excess of $1.5 billion. Many of its productions lines are very labour intensive; a large number involve "bin-picking". The Corporate Advanced Technology Group (CATG) was originally set up to improve motor efficiency using digital electronics. This has now expanded into the design and implementation of vision and inspection systems, process monitoring and control systems, and robotic systems design. The Group now numbers over 15 automation engineers; some are responsible for research and development, others for product commercialisation. Collectively they have great autonomy and answer directly to the board of directors. It has been estimated that the Group has already saved the corporation several millions of dollars. Recently CATG has concentrated on inspection systems with great success. A commercial version of its system is currently being marketed by Gallaher Associates and is capable when used for label inspection, of processing over 300 labels per minute. It was interesting to learn that several robotic installations had been removed because the robots concerned (Unimation Pumas) were just not fast enough to cope with the cycle times required. It was obvious that there was tremendous scope for a robot with sufficient speed of operation.

The success of the Ponds CATG should be noted by other corporations. The importance of automation expertise cannot be understated and this was emphasised by a visit to the die-casting firm, "Doehler Jarvis" in Pottstown, Pennsylvania.

Doehler Jarvis

Robots were first installed in Pottstown in 1964 and there are now almost 40, mainly involved in aluminium die-casting work. Indirectly Doehler has suffered from being reliant on Unimation for systems engineering. Although the robots themselves are impressive, some of the other aspects of the firm's die-casting are inefficient. Doehler has not taken advantage of microprocessors to control furnace temperature for example. The company's lack of in-house automation engineers contrasted with the situation at Metal Castings in Worcester where a small group of automation engineers has been highly successful in automating die-casting. Not only have they set up robotic cells but have also designed microprocessor-based control systems and have even designed their own robotic dispenser of molten metal. Doehler were just beginning to realise that they were going to have to increase their automation expertise to remain competitive.

ROBOT MANUFACTURING AND MARKETING

Issues which are currently important in this area include:

a) The emergence of GMF Robotics and the influence of aggressive marketing.
b) The licensing of foreign robots.
c) The identification and domination of specific markets and applications by small manufacturers.
d) Electric vs. hydralic drives.

GMF

Recent figures published by Prudential Bache securities (see [1]), confirm the rapid emergence of GMF Robotics. These figures predict that in 1984 GMF will have a larger share of the US robot market than any other company, with sales in excess of $60 million. This success is amazing when one considers that GMF was only set up in 1982. A joint collaboration between the General Motors Corporation and Fanuc Ltd., it involved a $5 million investment by both parties and the number of employees now exceeds 200. GMF sold more robots than Fanuc did in 1983 with more than 940 units. Almost 80% of these sales were to General Motors plants all over the world and thus almost 200 were sold outside GM during its first calendar year of operation. This has been achieved through efficient and aggressive marketing aswell as good applications engineering. GMF has an enthusiastic team with representatives in all regions of the USA who constantly monitor and report on user reactions and potential requirements. In this way it feels it can identify trends and rapidly respond to them. A good example of this was the instigation by GMF of the S-360 robot series for spot and arc welding applications. GMF identified the need for the robot and Fanuc responded by designing and developing it inside 4 months. The Company is investing in considerable research and development to ensure that it remains a market leader in years to come. It is developing a VAX based off-line programming system in collaboration with DEC aswell as its own vision system. In accord with recent predictions by Automatix, it sees Computer Integrated Manufacture as an important area for expansion.

GMF has made a success of selling foreign-built robots. One can attribute this to its large investment and operation, its aggressive marketing and its unique relationship with Fanuc in which it is able to influence strongly which robots Fanuc produce. However, in general the licensing of foreign robots was seen as a short term solution with the following disadvantages:

a) Interfacing problems and the realisation that the true value of advanced sensors and applications packages developed by Universities and Corporations will only be realised if they can be readily and cheaply interfaced to a robot's control system. This is not always possible with foreign-designed robots.
b) Inefficient response to market requirements. Unless the licensees start manufacturing they will in general be dependent upon the suppliers dictating future applications and markets. Quite often the licensees can identify definite growth areas but lack the in-house expertise to take advantage of the situation.
c) Competition from other licensees with the same product. For example GE currently compete with Automatix and Hitachi America to sell the Hitachi welding robot.

These are some of the reasons why a number of Corporations are thinking hard about foreign licensing and GE for example is making a big effort to develop its own robot and controllers.

Control Automation

Control Automation at Princeton was founded in 1980 and currently has 60 employees. Rather than produce a robot to compete with the "masses" CA has focussed on the pcb industry and its products show great promise. It has developed a highly accurate cartesian robot, the "mini-sembler", for pcb component insertion. Each cartesian axis is accurate to 1/1000 inch. The problem of leadscrew resonances has been overcome by using a fixed, tensioned leadscrew and by driving a hollow shaft DC motor along it. This also has the advantage that smaller motors are required than with conventional leadscrew driven systems. The "mini-sembler" retails at $37,000 and has