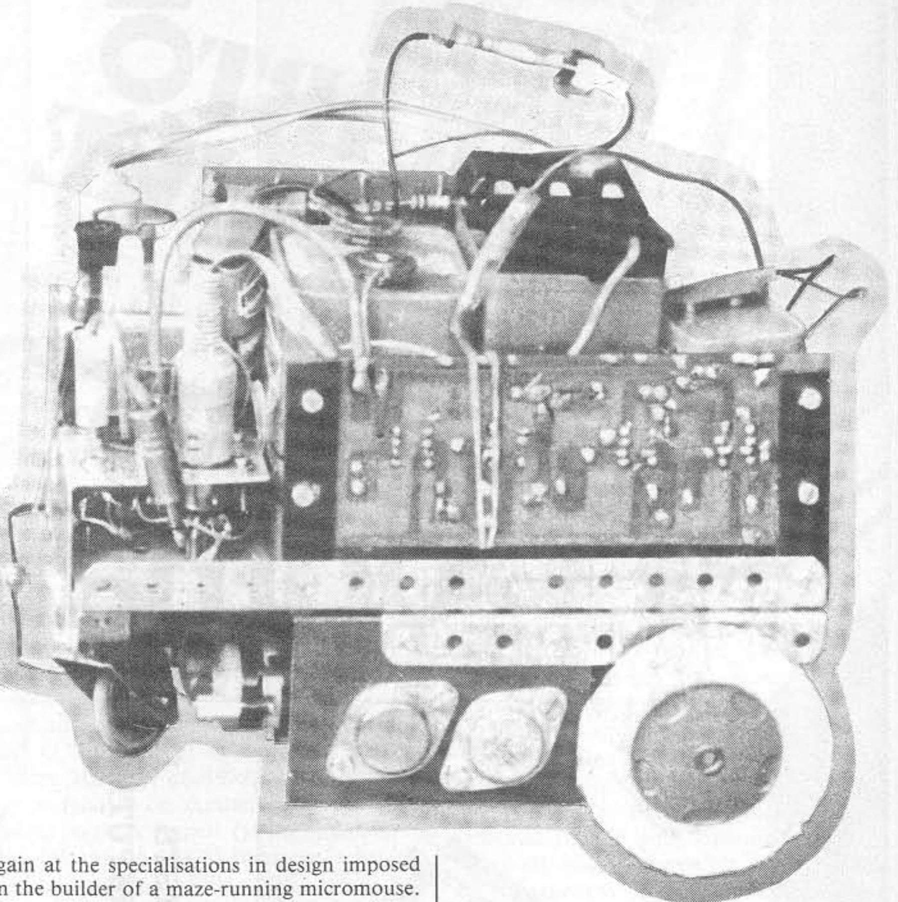
What rough beast, its hour come round at last . . .

. . . slouches towards the centre to be born? With an electronic memory, who needs a ball of twine and a female accomplice? Don't be amazed, there's no bull in our introduction to robotics.



by Mark Witkowski

***Practical Computing* and Euromocro invite you to step into the 1980s and design your own robot — sixty years after Karel Capek coined the word. It's a challenge the talented do-it-yourselfer can't refuse. This background article is the first in a series on the science of robotics.**

TWO 'MICROMOUSE' — type contests that were so successful in the States are included in the four sections of the Euromicro — *PC* contest to be held in the autumn of this year.

These will be run under the rules and regulations laid down by the American Institute of Electrical and Electronic Engineers (IEEE) magazine *Spectrum*. A robot 'micromouse' has to be designed and built to run a maze constructed to strict specifications. These rules and specifications are available from *PC*.

In addition to a section in which the micromouse must run the maze in the shortest time, a second section is open to mice that can explore and learn the maze and then use this information to find the optimal path through the maze from the start in one corner to the finish in the maze centre.

This has much to commend it as competitions go; the rules are well defined and the construction of a mouse is well within the resources of most individuals and small groups. Bear in mind that *Spectrum* has been running this type of competition for some years now, so there are already many tried and tested mouse designs.

Allen (78) gives details of just three of the entrants in the 1977-79 trials. These three, the 'Moonlight Special', 'Microbot' and 'Charlotte' recorded times through the maze as low as 51.4 seconds, though several minutes was a more typical time. Each had a microprocessor on board, two had Z80's and one an Intel 8748. Later in the series, we will look again at the specialisations in design imposed on the builder of a maze-running micromouse.

In addition, the new *PC* competition includes a section for 'free-style' robots, and this is a golden opportunty for the robot enthusiast to show some real ingenuity in the choice of robot, its design and design implementation. This first article discusses the various types of robot that have already been built and are in use. From these you should be able to choose some aspect of robotics that takes your fancy.

As you will see, there is plenty going on in one way or another. The rules of the competition are sufficiently flexible to accept equally innovation in the form of a totally new idea or improvements to existing ones. Future articles will be dedicated to a summary of the multiple skills that are needed, with practical hints on how to go about building robots, although we do not intend to provide a 'constructional' design.

To complete a robot project using a microprocessor will involve some mechanical construction, some electronics to interface processor to wheels and monitor any sensors; programming to write the control software; a certain quantity of luck; and not a little perseverance. In terms of the flexibility offered to small 'hobby' robots, microprocessors hold out a considerable improvement over machines that are wholly hardwired.

The most famous of these hardwired automatons must be Grey Walter's *Machina speculatrix* (Walter 53), which showed some interesting, if limited, light-seeking behaviour. Since then, most hobby electronics magazines have produced their own design or designs (eg Brown 69, Brown 71 and Galitz 72, who produced machines called EMMA, ZEE! and Cyclops). The behaviour of such a machine (shown in photograph one) was based on that of the planarian, and its control strategy closely modelled on biological principles.

The dictionary definition of robot is that of a mechanical man, or an automaton with some human-like quality. The word is usually thought to have entered the English language after a play by Karel Capek called *R.U.R. (Rossums Universal Robots)* which was trans-

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lated from Czech in the early Twenties. In Czech the word 'robota' means statute labour or servitude, and is therefore well applied to machines manufactured in human form to do manual labour. As with most fiction concerning robots it is something of a cautionary tale. Interestingly most of the friction between people and robots in fiction results from robots being sufficiently intelligent to be a nuisance. In fact, any current conflict appears to stem from exactly the opposite cause — very stupid robots doing exactly as they are told.

By far the most successful application of robots to date has been their use in industry. For the numbers used, hours of work completed and usefulness, they are far ahead of any other form of robot usage. They are not, of course, suitable for every aspect of manufacturing, but they are currently used in many industrial processes for moving partly-completed objects between stages, die-casting, materials handling and palletisation, machine-tool loading, welding and paint-spraying. Photographs two to seven show a small selection of the many makes and types on the market.

Pick-and-place

Photograph two shows a Unimate 4000-Series pick-and-place industrial arm. It has a maximum reach of nearly three metres, with about 1.3 metres variable, a horizontal sweep of 200 degrees and a vertical sweep of 50 degrees, with a lifting capability of up to 175kg. Typical robot payloads vary from 10 to 100 kilogrammes (from data sheets given in Rooks 72 and also Abraham, Stewart and Shum 1977). The hand of the Unimate is interchangeable for a wide variety of tasks — the photograph shows a sheet-metal lifter.

Photograph three shows a Hall Automation robot with a torch attachment. Photograph four shows a general view of the DeVilbiss-Trallfa paint-spraying robot. The control unit for this robot, photograph five, shows the tape units used to store the sequence of spraying actions ready for playback.

A key (leftmost unit on the control panel, second row down) can either be set to 'Teach' or 'Repeat'. In 'teach' mode, a handle is attached to the end of the arm and the machine is led through the desired sequence of movements by a skilled operator. When the work-piece is satisfactorily sprayed, the handle is removed, the switch turned to 'repeat' and the machine will reproduce the sequence, either as a 'one-shot' continuously or under the command of a switch or photocell that indicates when a new work piece is aligned, ready in front of the robot.

Photograph six shows a pneumatic arm, interesting mainly for its fluid logic controller (photograph seven) — quite a way removed from microprocessor control!

An electric beam arm manufactured by the British United Shoe Manufacturing Co can be raised, lowered and rotated on its vertical pillar as well as moved in and out. The wrist at the end of the arm can be rotated, and the gripper rotated in two dimensions.

Point to Point (PTP) operation differs from that used in spraying or welding robots. These use continuous path — all intermediate points are recorded. A typical control unit would offer in the region of 1024 points or 500 inches of continuous-path operation.

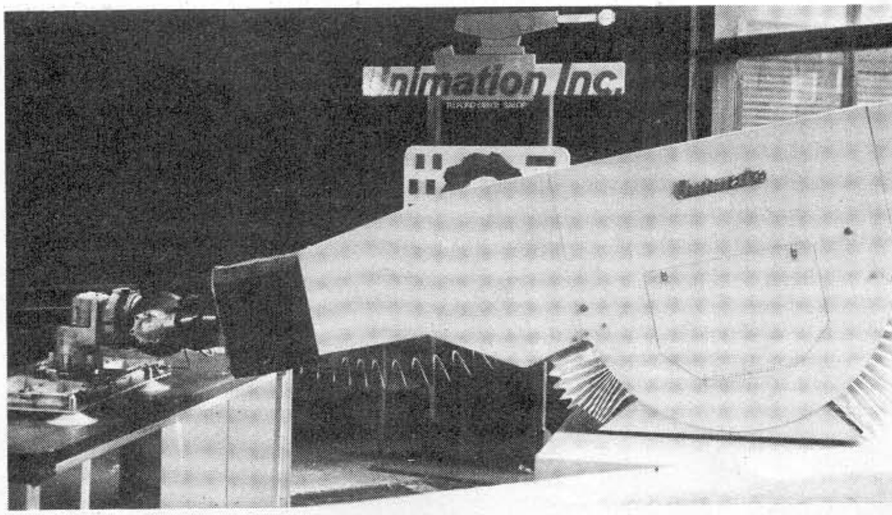

Figure 2: Unimate 4000-Series pick-and-place arm.

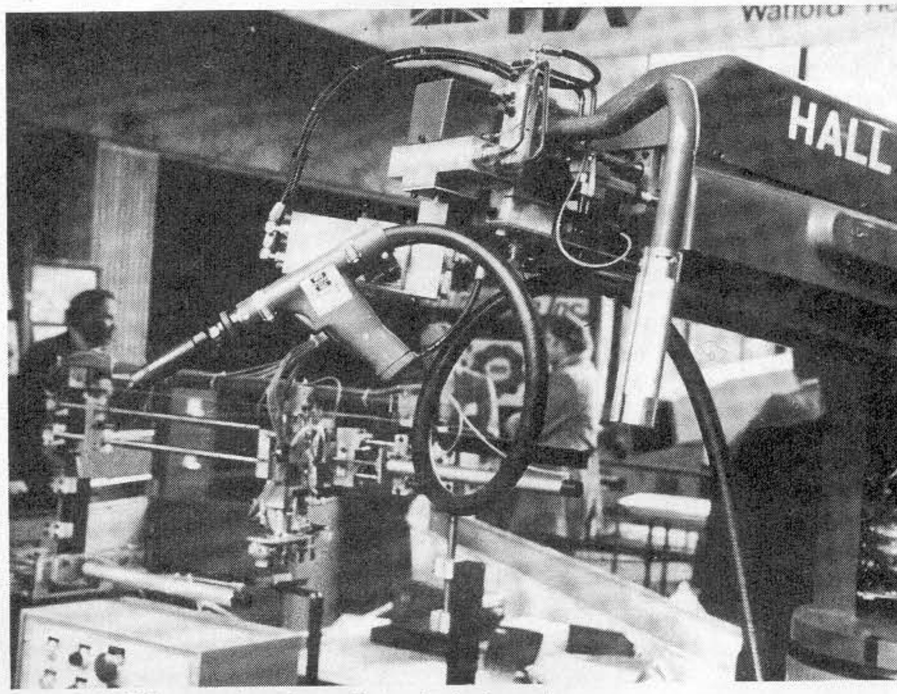

Figure 3: Hall Automation robot with torch attachment.

There are many reasons why robots may be desirable in industry. They find obvious applicability in those industries that are dangerous, or unpleasant for people to work in. Undersea, nuclear power-plants and mining all fall into this category. A robot also remains oblivious to tasks where heavy or hot loads are to be transported, to high levels of noise, or where noxious fumes are present. Robots are ideal where the work to be done is of a highly repetitive nature, requiring no skill from a person, and as a result are undesirable jobs.

Industrial robots are sold as a cost-effective method of introducing a higher degree of automation into processes where the production run is not high enough to warrant the full expense of total 'hard' automation. Robot manufactures will stress the cost savings over either people or specialist machines (Engleburger 79).

Grounds for the introduction of an industrial robot on the factory floor might include lower initial cost than 'hard' automation and lower running costs — than either people or other types of machines. Reliability is good and work-rate predictable. Unimation quote an up-time of "better than 98%". It is versatile too, and can be reprogrammed for other tasks where hard automation would have to be scrapped when the run is finished.

Zermio, Molesley and Braun (79) give a more comprehensive list of robot applications, and review various surveys that have been completed as to why manufacturers actually introduced robots in the specific application of spraying and coating. They also estimate that there are about 8000 robots in industry worldwide, 3000 of them in Japan, 2500 in the USA and 2000 in Europe. Of the European robot-using countries, Sweden and West Germany have about 600 each, although estimates very considerably, and Italy about 400.

The United Kingdom would only seem to have about 70 such machines and is the only country to show a reduction in the number since 1975. Interest in robotics, however, remains high in the UK and in the year September 1979 to November 1980, seven out of 19 international conferences and exhibitions listed in the *Industrial Robot* journal are in England.

As yet, sensing and feedback play only a

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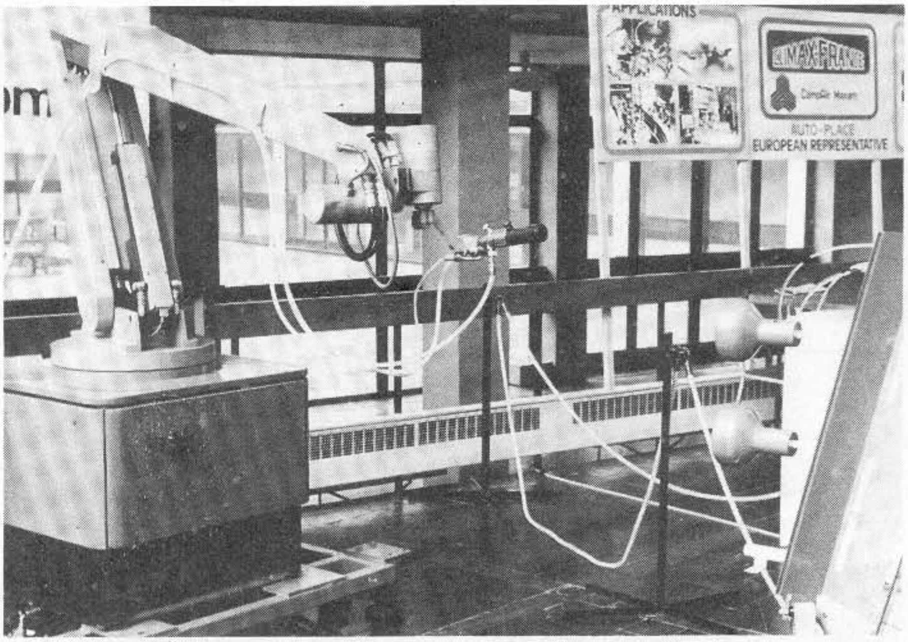

Figure 4: DeVillbiss-Trallfa paint-spraying robot.

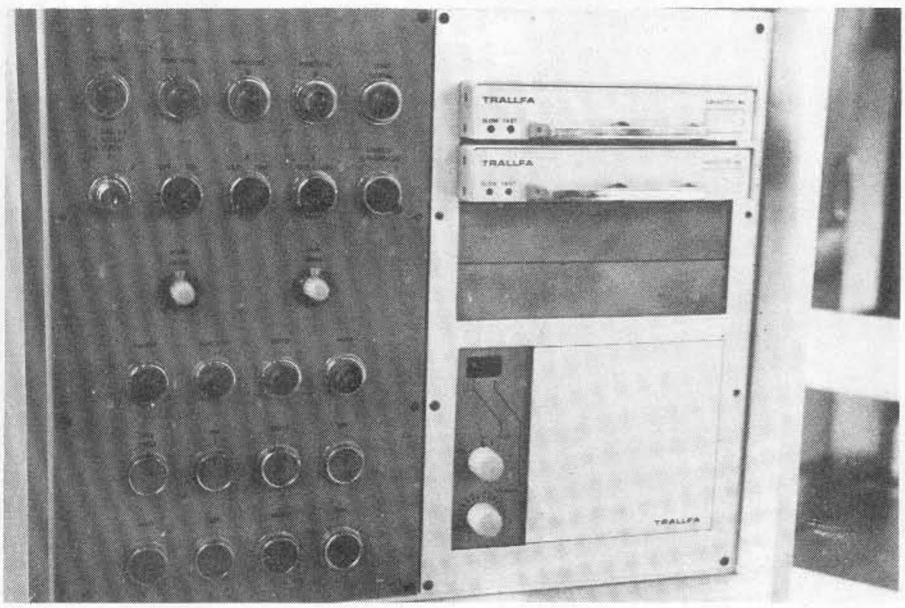

Figure 5: Control unit for paint-sprayer.

minor part in industrial robotics; they may be used either to guide the robot more effectively in situations where the work-piece is presented unpredictably, and increase the safety margins, both for people who work in close proximity to robots and other machines. These sensors tend to be rather fragile and in harsh industrial setting would soon be damaged.

It is also remarkably difficult to design sensors that really do detect all the things they should. Furthermore, the amount of computer power required to interpret this information rises sharply, and programmers with these specialist skills are rare. Wang and Will (78), of IBM describe some work on sensor development that might be generally applicable. Perkins (78), at General Motors, has been looking at the more specific problem of recognising parts used in the manufacture of cars with digitised TV pictures.

Robot 'brains' are now very much the province of the computer scientists, more specifically that of artificial intelligence research. Those of you who are following the current series on artificial intelligence in *Practical Computing* will notice that there is little danger of the 'super-intelligent' machine appearing any too soon to give us all a hard time. This is quite distinct from super-powerful machines being controlled by intelligent men.

There is a growing number of artificial intelligence researchers who feel one of the main limitations to progress in their field is that the only contact the program has with the outside world that it must be intelligent about, and the people it must communicate with, is through a teletype device.

While it is no doubt theoretically possible to input every scrap of knowledge the program must have, in this way it does show a number of major limitations. Apart from being incredibly hard work, it also deprives the machine of many potent sources of information, firstly the ability to process raw data, like that which pours in through our eyes, ears, nose, mouth and skin, and secondly the program's inability to make important correlations between different information received through different senses about the same event.

It is the lack of muscles and limbs that really restricts. These can be used to check the validity of the program's observations, deductions and assumptions. However complete a logical proof appears, the result is still rubbish if any of the axioms upon which it is based is false, or even inapplicable within the context of that proof.

Robots provide the eyes, ears, skin (and any one of a hundred different other senses modern instrumentation techniques can provide), as well as the muscles to move and behave that a *complete* artificial intelligence program will need. We would have no hesitation in saying that an example of natural intelligence would be at a severe disadvantage without these abilities.

There are still relatively few robots involved in artificial intelligence research. Some researchers will not use them on principle, others feel they do not need them; linguists, for instance, have enough problems without becoming involved with all the electronics and mechanics required.

Pre-processed data

Some programs require their data in a highly preprocessed form and in any case would not work fast enough to handle the data rates the real world produces. Even simple sensory systems such as tough and range-finders must be scanned so often if transitory effects are not to be missed that the complete power of a minicomputer can easily be used up just processing this.

When it comes to vision input from TV camera, the problem becomes horrendous.

Consider that a 100 × 100 retina matrix, scanned 10 times a second, which is less than 3% of the resolution of an ordinary television, would only allow two or three machine instructions per picture point on an ordinary minicomputer. It may actually take several hundred instructions per point to analyse the picture properly.

Two projects that used both robots and television input to computers were the Stanford Shakey project, which has been described as the first complete robot system (there is a brief description of the project in Jackson 74). Freddy at Edinburgh University is the second (Barrow & Crawford 72, Ambler et al 75 and Michie 79).

Shakey was a free-ranging robot with a camera that existed in a suite of rooms. Its control was provided by a suite of programs, a specialised vision program, a theorem prover that planned its actions according to pre-set goals, and a low-level controller to convert the plans produced into real actions.

Freddy was a hand-eye system, a manipulator and TV camera that could be used to construct toy models from their parts. Freddy had an interesting construction.

Shakey and Freddy

The gripper was suspended from the roof and could grip, turn and move up and down. A particular object would be selected by moving the floor in an X or Y direction. Both of these projects suffered due to a reversal in government funding policy towards artificial intelligence and robotics in the early Seventies.

One mobile robot we have examined has seen a good deal of service in artificial intelligence research over the past few years. It is hardly as grand as Shakey or Freddy, mainly because it has never been funded properly — even though it has been used by a number of funded projects.

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In one sense this has been an advantage because it was protected from the more abrupt changes of heart by funding agencies. Unfortunately the quality of engineering required for this type of work was not up to scratch for lack of cash.

Over the years, facilities have been added as and when possible, and all the initial problems are pretty well solved. The vehicle has no 'intelligence' of its own. It is just a motorised base with integral power supply (batteries) and a multi-way analogue-to-digital converter. Into these A/D channels are plugged a range of standard sensors, with plenty of spare capacity to add new ones required by any particular project.

Every single action it makes is under the control of one or more computers. Communication is via the thin wire visible in the photograph. In the five years since the project was started it has been interfaced to a wide range of micro, mini and main-frame computers. Programming languages ranging from 6800 assembler to POP-2, through Fortran, C, RTL/2 and Algol-68 have all been used — depending on the preferences and experience of each of the users. This set-up is sufficiently versatile to allow a wide range of robotic experiments to be carried out. These have included such topics as (at undergraduate, post-graduate and research levels) map-building and best-path generation, navigation using only on-board sensors and external coordinate generating devices in separate experiments. Tracking and limited pattern recognition using the 32 by 32 binary camera have been investigated.

Mainstream research

Long-term research has been based on biological modelling, learning by production rule and more generalised learning and problem solving techniques, this latter project forming a complete robotic system. Apart from this, considerable effort has gone into the construction of the human interface end of the business. This includes the design of programming languages, computer systems and inter-computer communication.

Most recently, the mainstream of our research has taken a path more closely aligned with the requirements of man-robot co-operation, with man, robot and computer working as a team to solve problems: robots with their superior strength, accuracy and special adaptions to the task, the computer to analyse data from specialised transducers and for fine control, also to prepare sensory data for presentation to the human in its most helpful form. The man is there to supervise, guide and be prepared for the unexpected.

The current machine is not designed for this and we are busy designing and constructing a vehicle which is a motorised base, with two multi-axis arms and a TV system capable of digitising a 256 by 198 point picture in one-fifth of a second. Computer power is provided by three 64K LSI 11s.

From the amateur point of view, there are many robot designs that could from the basis of a home-brew machine. For the maze contest, the restrictions to the design are quite severe; it must perform a fixed task in a well-defined arena. For a more free-style robot, the first decision to be taken is about the form of the robot.

Close attention must be paid to the mechanical design of an industrial-arm type of robot, but these have been attempted in the home. Most have five or six degrees of freedom and there are two popular configurations. Some follow the DeVillbis-Trallfa paint sprayer, and model the human arm, with shoulder, elbow and wrist, but if you do not have access to a full machine-shop in which to build it, a type which features some combination of cartesian joints that slide the polar ones that swivel (eg the British United Shoe Manufacturing Co) may be more appropriate.

Figure 6: Pneumatic arm . . .

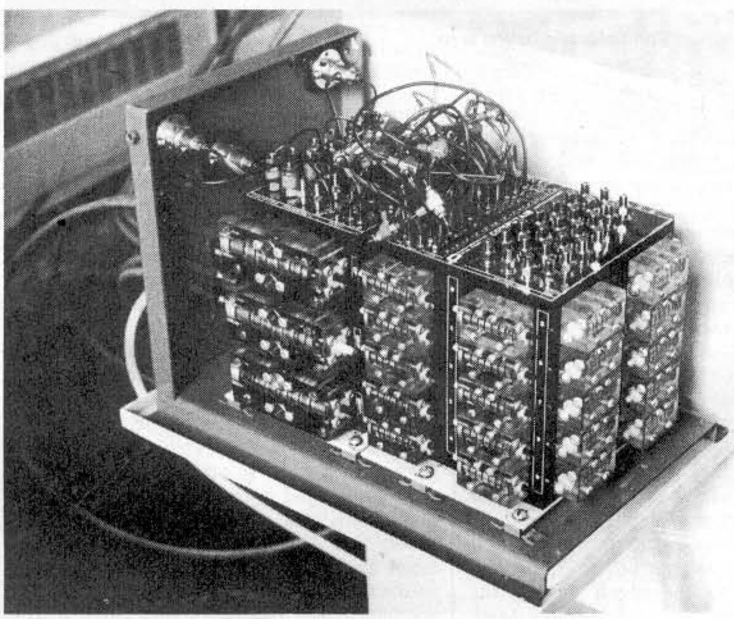

Figure 7: . . . and its fluid logic controller

Electric motors are a useful compromise between power output, availability, controllability and ease of interfacing to a processor. Stepping motors provide adequate accuracy for open-loop control, though if they are used at shoulder and elbow joints, the weight of the remainder of the arm and hand may require rather larger and hence more expensive motors.

Be careful that the design eventually chosen can both reach all the places you want and that the larger joints have a comfortable margin of strength and power. The arm must not only be able to lift its own weight, but also that of some payload.

For good power-to-weight ratios and high speeds of operation, hydraulics and pneumatics are an excellent choice, and they are much in evidence in industrial units. They do tend to be expensive — particularly proportional valves and pumps. They can also be very powerful, so a solid design is called for if the slightest software fault is not to pull the whole thing apart.

In an 'industrial'-style competition entry, solid, well-engineered designs start with an advantage. Nothing is more disconcerting than a shower of 6 b.a. nuts and bolts each time the thing moves. Real credit, however, will surely go to the design that incorporates ingenious and appropriate sensing, but is also easy to use on the shop floor; when it comes down to brass tacks, good engineering only takes money — good ideas are precious.

You would be up with the leaders if the arm could pick an item in a random orientation off a conveyor belt and leave it in a specified place and orientation. If the arm picked the object out of a hopper full of them, it would be ahead; if it can do it at about the same speed as a person, patent it — quickly. Judges will

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Figure 8: British United Shoe electric beam arm

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probably look for a design which is versatile, quick to adapt to a new task, and requires minimal modifications to the gripper between jobs.

Many people and organisations have proposed robots to help in the home. Every so often the news is full of a robot to be "programmable for a range of household tasks", available "soon" (always "soon"), for "a few thousand pounds". Such announcements are invariably met with a quite uncharitable degree of cynicism from those researching into robotics; still, one day, 'soon'!

The task is not impossible, just damn difficult; one could try to design a vacuuming machine. It might just go down better with the loved one than a robot that spills hot hydraulic fluid over the carpet. Criteria for a good hoovering robot would include its hoovering everywhere, right to the edges, moving the furniture, sometimes, not knocking the Ming vase off its stand or running over the cat sleeping in the most inconvenient place possible.

Androids and golems

Robots have been used in education too. A good example is the Logo project from the Massachusetts Institute of Technology (MIT) (Papert 71). These small computer-controlled Turtles have been used to teach a range of concepts to young children in computing, mathematics and music. The children can use the Logo programming language to control and then program the robot to give them insights into processes of computing and computers.

These techniques are used successfully to hold the interest of the children in traditionally unpopular or difficult subjects. Competition entrants who are teachers or interested in education could well try something along these lines. Quite a lot of work has already been done, so better read around a bit.

Assorted automatons, androids, golems, robots and bionic entities are frequently featured in stories, films, plays and pictures and there is no reason why these should not form a valid part of any robot scheme. Jasia Reichardt's recent book *Robots: Fact, Fiction & Prediction* (Reichardt 78) treats robotics mianly from the artist's point of view.

An example of robots making art, as opposed to being in art, is provided by Harold Cohen's work. He uses a turtle, with pen attached to its underside to draw child-like pictures under the control of a PDP 11/40. These pictures may cover over one hundred square feet. The program consists of about 300 interconnected rules about the artwork it is to produce (Lansdown 78).

Robots and medical prosthetics, artificial limbs, are closely linked (Todd 78), and the full mechanisation of wheelchairs would almost certainly depend on robotic principles. Many of the artificial intelligence applications of robots in the past involved very large investments in computer power. Shakey, for instance, used a PDP 15 for local control, connected to a specially paged PDP10. Freddie used a local Honeywell H316 and an ICL 4130, ours uses a local PDP11/10 connected to an ICL 1904S.

The much considered and computed deliberations and then actions of any of these machines could not be described as rapid or real-time. This is partly because of the languages used to implement the high-level ('intelligent') end of the system. They tend to be relatively slow interpreted languages, used not for their efficiency, but for the power they provide the programmer. It is possible that by careful recoding of these ideas, probably with some reduction in complexity, considerable improvements in performance could be obtained.

The amateur is well situated to take the best ideas of artificial intelligence and modify them into a useable form. A program that could translate instructions in English to the correct robot actions, or one that could plan a course of robot actions using knowledge about the environment, giving reasons for each choice, or a robot that modified its behaviour according to sensory information in a sensible fashion, should all be welcome entries. More than this, they would all be worthwhile work in their own right.

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