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Reports and Surveys

ADVANCES IN AUTOMATION

1. Miniature machines

Cambridge UK scientists are attempting to cut groves in silicon chips just wide enough to contain one molecule of DNA. If successful it would mean that a hand-held device using such chips could be programmed to read the entire sequence of human DNA. Such computers could, for example, be built to identify causes of any sudden infectious diseases with a diagnosis obtained in minutes rather than in the days it could take using present-day technology. The report of these researches suggests that the whole process could then be a more controlled one with the readings taken being more precise. A comparison with current channel cutting methods was also given. Apparently, channels in a chip are normally cut to a measure of millionths of a metre, whilst the Cambridge researchers are now down to 100 millionth of a metre and confidently hope to achieve 10 billionths of a metre.

2. A legless human-shaped robot called Cog

Dr Rodney Brooks, the Director of the Artificial Intelligence Laboratory, at the Massachusetts Institute of Technology, USA, has created Cog a legless human-shaped robot. We are told that when approached the robot swivels its head in a disconcertingly human gesture, and stares at them. Visitors to the Laboratory inevitably stare back and researchers say ‘for an instant they get the eerie sense that there has been a meeting of minds’. Cogs unsettling gaze is little more than a clever illusion. Dr Brooks and his graduate students, however, believe they have taken the first steps towards creating a truly intelligent machine. Dr Brooks says that the key to achieving human intelligence is to:

“build a machine that experiences the world in much the way a human being does. This requires not only the ability to sense and manipulate the physical world, but the social world as well, since from infancy on, almost all of what humans learn comes about from human reaction. And the first step, bridging the gap between humans and machines, is eye contact.”

He also believes that the majority of artificial intelligence researchers pursue an approach that is ‘Good old-fashioned *A.I.*’. This approach is one where it is assumed that the best way to make a computer intelligent is to cram it full of knowledge about the real world and methods to manipulate it. His philisophy is to build a robot based not on data input, but on experiencing the world as humans do. Before making such a robot Dr Brooks spent more than a decade building robotic insects that could ‘freely scurry about’ and explore his laboratory. Over the past five years, with the help of his students, he has built Cog a robot with a skeletal aluminium figure with a swiveling, octoganol head perched on broad, motor-studded shoulders from which a pair of powerful arms that end with simple, fingerless hands. Cog, it was decided would not have legs. The robots eyes consist of two pairs of video cameras, one wide-angled, the other with a narrower focus to simulate human vision, which is far more sensitive in the middle than on the edges. They move much as humas human eyes do. The output of these cameras is displayed on a bank of amber monitors mounted on a rack behind the robot. Cog also has tiny microphone ears, gyroscopes that work much like the inner ear to provide a sense of up and down, as well as various sensors to report the position of its limbs. The ‘brains’ are a network of Pentium computers mounted on a rack nearby.

So far the developers say that Cog’s achievements are modest, though they believe impressive by the standards of robotics. In brief, Cog can already make eye contact, track motion by swivelling head and eyes, and even distinguish humans from less interesting objects. To expand his theories Dr Brooks has given Cog a sister called Kismet, who is essentially training the human to be a good teacher. Kismet has a simple set of moods, like happiness, interest, anger, fear, disgust or surprise, that can be expressed on its face. The result of this research could be the production of a humanoid robot. The current robots Cog and Kismet will act as research platforms to investigate theories of the human mind.

BUILDING SMALL ROBOTS

1. Swedish research

Researchers worldwide are conducting research to produce small robots with many projects concerned with developing really small robotic devices. We know that in many medical research projects microscopic robots have been produced. Now, however, in Sweden it is reported that ‘robot insects’ are being developed with the aim of building devices that are only one millimetre long. The potential applications for such systems is enormous.

Often reports from our current breed of scientific reseachers are exaggerated, not because they are fraudulent in their claims, but rather that the chances of getting research funding without the publicity gained by some eye-catching media report is more unlikely. Now there are so

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many more universities and research institutes in the world competition for research funds has never been so fraught.

In Sweden, however, we are told that 'robot insects' have actually been developed by researchers at the Royal Institute of Technology, Stockholm. The Institute's research team reports that they have already built a prototype robot that is only 1 cm long, and that they believe that their research breakthrough will allow them to build robots that are less than a millimetre long. They describe their 'insect-like robots' as having eight legs and the ability to move at speeds of 1 cm per second. The Institute's robotic researchers claim that they have found a new way to control the tiny robot's legs, allowing them to be shrunk far more than other robot legs. A report that describes the construction of the 'insect robots' says that:

". . . they are made from a layer of silicon coated on a membrane. Grooves are cut into the membrane and filled with a plastic material along with tiny heaters. It is when the heaters are activated, the plastic shrinks, causing the grooves to bend forming the insects legs. Altering the current through the legs makes them move, allowing the insect to walk."

The researchers say that the robots can be produced cheaply, since they can be made in a similar process to that used for the manufacture of silicon chips for computers. It is suggested that each robot would cost less than £1. The computer-chip type processing techniques would allow up to 10,000 robots to be made at once using several layers of silicon wafers so the developers claim.

2. Innovative applications

The Swedish inventor of the robot Thorbjorn Ebfors has suggested that at first they could be used as miniature factory workers that will build tiny electronic components. The inventor, in an interview reported in the UK Sunday Times (October 1999) said that:

"The Japanese are particularly keen on building micro-factories to produce tiny components and will be able to use our leg technology to make robot builders that can work on a conveyor line."

Another application that Dr. Ebfors envisages and recorded in the same interview concerned the use of the robots as a 'robot spy'. He said that:

"It is fairly straightforward to build a video camera on top of the 'insect', which could then carry it into enemy territory. Of course, because of its size it would be fairly easy to disguise them as 'real' insects."

One of the problems encountered with these small robots at present is that they are controlled through tiny wires. The next breakthrough will be when they are controlled by their own electronics systems so that they could work entirely on their own.

The Swedish team seem to accept that shrinking the robot even smaller is no problem, but realise that at present the rest of the components need also to be reduced and the technology to do that is still being developed.

It would appear that with some of the technology at this stage the advent of the 'insect' robot is assured. The Royal Institute does, however, seek commercial backing to develop the project further. They say they have or will have all the technology needed, and claim that no one else has it, but still need commercial partners to develop, manufacture and market the research.

CONTROL AND AUTOMATION SYSTEMS

2000 is going to be the year of opportunity for high-flying companies in the Automation and Control Systems industry, according to the *1st edition 2000 of the Plimsoll Portfolio Analysis: Automation and Control Systems*.*

The analysis indicates that it believes:

> 48 companies are shaping the industry as we enter the 21st century. What is so special about them is that they have achieved an amazing 15% or better sales growth in each of the last three years. Without a doubt, they have been doing something different. This is an industry where the average sales growth last year was an uninspired 4.1%. Some of these opportunists will need to improve financially, but by capturing the market they are proving that a company can be exceptional even in the Automation and Control Systems industry.

Based on the data the compilers of the portfolio analysis have concluded that:

> For the remaining 628 companies, simply hanging on to current sales is going to be a problem. 44% of the industry failed to grow at all last year and a massive quarter of the industry saw sales decline by 29%. But at least some have good cash reserves that will help them through 2000. Many of these will need to adopt a new strategy.

The compilers also consider a range of strategies and suggest that:

> Perhaps their strategy might be to acquire a company. Plimsoll's latest edition names 31 companies called '*Potentially desirable to own*' which includes 10 major players. Estimates suggest at least one of these will change hands next year. However, the others listed are less well-known smaller companies.

The authors also make a prediction that:

> 2000 will see some companies fail, but this will release opportunity for the remainder. In analysing the 676 players in the Automation and Control Systems industry through the graphical Plimsoll Model, the individual strengths and weaknesses of every company are revealed as well as the trend in their performance over the last four years.

Also named are other exceptional companies such as '*Best Trading Partners*', '*Best Profit Makers*', '*Cash Rich Companies*', '*Leaders in Efficiency*' etc.

The 1st Edition 2000 also contains Plimsoll's Top 10 most aggressive companies in sales growth in the Automation and Control industry. They are:

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1. Digitron Ltd
2. Motoman Robotics (UK) Ltd
3. Gamma Automation Controls Ltd
4. S L C (Automation) Ltd
5. Novisystems Ltd
6. Teradyne Ltd
7. Jaltek Systems Ltd
8. Process Automation & Computer Systems Ltd
9. Daifuku Europe Ltd
10. Edwards Automation Ltd

MICRO ROBOT AIR DEVICES

1. Micro air vehicles (MAVs)

It is reported that a very large number of micro air vehicles (MAVs) are being developed worldwide, and particularly in the United States. MAVs are small enough to be held in the hand with many being only six inches long. Further research is in hand to make them capable of travelling long distances, perhaps with some form of rocket propelant. The research appears to envisage such devices holding these insect-sized cameras and taking pictures of ground targets from about 300′. One such development, still at an experimental stage, is taking place at the US Naval Research Laboratory. The prototype, we are told, has electric motors on each wingtip to drive folding propellers. The researchers say it will be part of the development of such MAVs for jamming radar systems. The Naval Research Laboratory has a tactical electronic warfare division and this unit is interested in designing a MAV with enough power for flights of up to 30 minutes. The device would be powered by a ‘pencil-shaped motor’ that would weigh no more than six grammes. A speed of 30 feet a second, researchers believe, could be achieved.

The MAV would be a mini-robot device that would greatly contribute to the research programme initiated in the 1990s. The US Defence Advanced Research Projects Agency (DARPA) started a four-year MAV programme that cost some $35 million (about £23 million) in 1997. The hand-sized planes the programme set out to design and build were not to be more than six inches long, and the aim was to encourage the development of the appropriate technology as far as possible.

2. Role of MAVs

The report from Janes's International Defence Review highlights some of the roles the developed MAVs could carry out. It is because of their light weight, low cost, and inherently stealthy operations in terms of noise, radar and visual signatures that they have the capability of carrying out unconventional missions. In addition, they could be used to detect and identify biological or chemical agents. Another important defence application would be their use as a radar-jammer. It could fly close enough to the target to be effective in, for example, an aircraft or missile sorti. Also a suggested role of providing a downed pilot with reconnaissance information or to transmit a signal for search and rescue forces has been investigated.

3. Development of MAVs

It has been estimated that the cost of such prototypes would be about $50,000 each (some £33,000), but, of course in production this could drop to around $5000 or even $1000.

Most readers will appreciate the big challenge that the design of such innovative devices present. The aerodynamics is a main one since because of their small size and low speed they will be operating in an environment that is familiar to small birds and large insects. Following this research methods have to be found to launch MAVs and many encouraging ideas are being investigated. These include placing them on the back of air-launched guided missiles, or even releasing them from unmanned air vehicles.

In parallel to this research an insect-sized camera is being developed to be carried on the MAVs. One specification is that the camera is to weigh less than one gramme and have an aperture of some 2.6 mm and be capable of receiving clear images from around a height of 300 feet. The ultimate device could well take the form of a microscopic robot plane driven by miniscule computers to control its flight and actions.

3. Development of micro-helicopters

A report from People's Republic of China describes the development of what is called ‘the world's smallest helicopter’. At the Jiatong University, Shanghai researchers have developed a small spy helicopter which is less than 3/4 inch long and has the capacity of landing on an area about 1/4 inch square. Like the US researchers the Chinese developers are also interested in equipping the device with a camera. As to its uses it too would be used for surveillance activities. The Chinese engineers boast that they are ahead of their US counterparts since they claim their small helicopter could gain entrance to a restricted area through a ‘crack in the wall’. This helicopter device is said to cost several thousands of pounds and is being developed for industrial surveillance as well as possible military use.

In the technical specifications produced and quoted by Jane's Defence Weekly, the engines are described as having six gears that allow the craft to land gently. The report says that at maximum power the engines turn at 25,000 rpm. There is still a great deal of work to be carried out on the small craft and currently the problem of steering it is the main obstacle. Such a micro-robot device will have many important uses.

REPORTS IN BRIEF

1. Compact KUKA robot is chosen

KUKA Welding Systems and Robot Limited is reputed to be one of the UK's leading integrators and suppliers of high technology industrial robots and automated production systems. It provides full turn key packages that range from single robot shells for welding, handling, cutting or adhesive laying applications to machine tending systems and palletising solutions, and fully integrated robot transfer lines for the automotive sector. Currently, De Marchi Engineering is using a compact, space-saving robot made

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by KUKA to weld safety critical components for the construction industry.

The Wiltshire-based company recently purchased a KUKA KR6/2 robot fitted with a plasma welding unit to produce a wide range of stainless and mild steel parts including bracket for safety harnesses.

KUKA supplied its 6 axis, 6 kg payload robot cell in an integral base structure so that it could be easily installed with the minimum disruption to De Marchi Engineering's production schedules.

The cell also included two fixed tables and weld power source together with an integral canopy for fume extraction. The cell is controlled by KUKA's powerful, hand-held, Windows-based Control Panel.

The plasma source is fully integrated into the robot controller so that all individual parameters can be programmed into the hand-held KUKA KCP control panel.

KUKA's plasma welding unit offers high welding speeds up to several times faster than TIG and a superior weld finish. In addition, a faster overall cycle time can be achieved which reduces the costs of consumables such as shielding gas.

Further details about the company and its range of robots and automated production systems can be obtained from: KUKA Welding Systems and Robot Ltd., Hereward Rise, Halesowen, West Midlands, B62 8AN. Tel: 0121–585 0800. e-mail: DebbieMcPR@aol.com

2. Gantry robots for complex production

French company Afma Robots* is a specialist in automation solutions. It has launched a 3 to 5 axis gantry-robot for industrial production of large and specific complex parts for special applications in the aeronautic industry. This gantry robot carries out both high precision cutting and 3D welding of parts. For the automotive sector, Afma Robots proposes a handling gantry for loading and unloading of high-speed machining tools. This unique gantry enables heavy loads of up to 1 tonne to be handled at very high speeds (120 m/min).

Mounted on four rigid reinforced concrete pillars, the laser robot alternately carries out cutting and orbital welding operations in 5 axes by changing the laser head. Parts of different shapes and sizes are held in a fixed position under the laser beam by another robot, which picks them from five supply points. The gantry's precision is greater than 0.1 mm per metre of displacement with repeatability of 0.02 mm.

Its rigid anti-vibration structure enables several technologies to be incorporated: laser, water jet, machining spindles or non-destructive controls. Cutting and welding uses a 2 kW CO_2 laser for titanium or stainless steel conduits. For work in 5 axes, the laser head turns around the part under the control of a joint-tracking optical system, which adjusts trajectory in real time. Cutting with a very high-pressure water-jet at 3,800 b is also possible, with or without abrasives, on parts in aluminium and composite machining and drilling of composite materials are used on monolithic or honeycomb aeroframes.

* Further information contact: French Technology/FTPB, 21–24 Grosvenor Place, London, SW1X 7TB, UK.
e-mail: dan.ray.ftpb@cfme-actim.com

Afma Robots provides telemaintenance on its equipment, as well as auxiliary functions such as management of laser parameters, checking of geometry, suction removal of filings, tooling configuration, laser head changing, loading of parts, water recycling etc. Afma Robots has perfected state-of-the-art laser welding and joint-tracking techniques. The geometric quality of parts handled by this multi-purpose gantry-robot resembles that obtained with machine-tools.

3. Automated listening post

Computer systems that could well be developed to recognise sounds are being developed at the University of Hull in the United Kingdom. It has been so successful that it has the potential of being able to recognise the sounds made by insects and could be used in a programme to save crops. The development of an automated listening post is also being investigated.

The 'bugging' system will enable gardeners, for example, to listen to insects and farmers to control insects that may be harmful to their crops.

The research team at Hull say they have developed a technique to feed the sounds made by bugs into a computer and convert them into a form that is recognisable as a speech pattern. They believe that their new computerised system is sensitive enough to detect an insect landing on a leaf. A researcher at the university said that:

> . . . while some insects just make a noise others communicate with each other. At the moment we are doing some work on whitefly which communicate by singing. We cannot normally hear it because the sound is sent along a leaf. But our sensors can pick it up.

Research is also being carried out on grasshoppers and crickets.

Computers have, of course, been used to recognise sounds and to be the centre of sophisticated speech recognition systems. In this research a computer system is used that recognises sounds by using speech recognition software. This converts the sounds into digital signals and the system, it is claimed, has the capacity to recognise and distinguish between 25 different species.

Potential applications are wide ranging and many important applications are currently being investigated. One such application involves the immediate recognition as to whether an insect will be harmful to crops. The computer system does this by sound analysis of the insect noises and generates a warning if the software program believes that they do pose a threat. Another project is investigating the development of an automated listening post that can be easily assembled, with the computer system housed in a portable box. The Hull University researchers say that a large number of companies and organisations have expressed interest in this innovative project.

4. Nanotechnologists predict the future

It is reported that nanotechnologists who construct their much publicised devices to a scale of a billionth of a metre, are producing even smaller things. At the University of

Washington, USA., a scientist has built what is described as the world's smallest railway. We are told that its carriages are made of protein filaments one-thousandth the diameter of a human hair. They run on tiny tracks made of Teflon, and shuttle invisibly from one station to another.

The future of nanotechnology is too bizarre to comprehend. Researchers in the field talk of constructions that involve making girders, wheels etc., which are just one millionth of a millimetre long. Already microelectronic mechanical machines with parts a thousandth of a millimetre across are now made by the million. They are produced for use in sensors that are used in, for example, airbags, computer joysticks and other applications where their small size makes them extremely sensitive to movement. Technological innovations in the future, we are told, that use nanotechnology will involve products that will be 1000 times smaller.

5. Important applications for robots in the nuclear industry

Robots have undoubtedly proved their worth in many of the diverse applications in which they have been involved. None more than in the nuclear industry where a combination of a dangerous environment for operators and the safety of communities and indeed the whole world produces great challenges.

The decommissioning of nuclear reactors is now an ongoing operation throughout the world as useful and safe lifespan comes to an end. In the United Kingdom, for example, engineers have begun to dismantle the irradiated core of Windscale's nuclear reactor. This, we are told, involves a decommissioning scheme costing £80 million. The dangers of carrying out such a scheme without the use of robots would be such that it could well prove impossible. Instead from a protected control room engineers can manipulate an £8 million robot that is capable of cutting, shearing and grinding through metal and graphite, by using a bank of television monitors for guidance. Teams of operators are able to use the robotic system to enter the nuclear reactor's Hot Box to retrieve abandoned neutron shield plugs. The plugs, which look like a series of innocuous metal rods, remain radioactive for some 18 years when Windscale has stopped generating electricity. The engineers at the reactor site aimed to fill 140 concrete boxes with the radioactive material. The boxes were stacked, three deep, in a special purpose built store on the site where they could, if necessary, remain entombed for the coming 100 years.

Windscale, which was opened in 1961, is the location for the UKs lead power-decommissioning exercise which has been designed to show how the nuclear industry can clean up 'its own mess'. The scheme is being financed by the UK Government, the European Union, and also the nuclear industry itself.

What it is hoped to prove is that the method of 'safestore', where old reactors are weatherproofed and left until the radiation levels have reduced to a more manageable level, is not the sole option. In the UK three old Magnox reactors have been stored in this way. Now if this scheme is a viable one it will provide a much needed alternative way of decommissioning.

6. New project brings hope

The task before the engineering teams is to remove 1,200 tonnes of immediate and low-level nuclear waste. To do this they have to work from the top of the reactor downwards, that is from the Hot Box, pressure vessel to the core, in what is described as a sequence of 'campaigns'. It is estimated that this will take some five years to complete. No one has claimed that it could be done without robots or, if it could, provided an estimate of how long it would take. It certainly would not provide the second much needed option for decommissioning.

This project, which is called the Windscale Advanced Gas-cooled Reactor (WAGR), will demonstrate conclusively, we are told, that the technology exists to transform the world's ageing nuclear power stations back to greenfield sites. A report on the use of robots for this work suggests that there is a race to win contracts for the work involved in decommissioning worldwide and particularly in America and Europe, including the countries in the former Soviet bloc, where the work is said to be worth a potential £100 billion. Environmentalists believe that this form of 'active decommissioning, of nuclear power stations as the only acceptable option and now the technology exists it is the option that they and the nuclear industry itself want to be activated. Obviously the technology has to be effectively demonstrated by the WAGR project and also the decision considered on economic grounds. As far as other countries are concerned, we all recognise that the problem of decommissioning is not a local or even a national one but a global concern. Countries, perhaps, without a 'green lobby' may well baulk at the cost and find 'weather proofing' old reactors a more attractive option. The £8 million robot which controls the removal of an irradiated core in a nuclear power station decommissioning process may not prove to be even a possible option, however environmentally friendly the resulting process has become.

7. Regaining public confidence

Researchers and developers in automation have provided the technology for the nuclear industry. This is now an opportunity, many environmentalists believe, for the industry to regain public confidence and support, at a time when in the U.K., many questions are being asked about the way in which such industries are monitored and controlled.

ROBOTICS WORLDWIDE

1. United Kingdom

Voice activated surgery in the UK

At the end of last year Europe's first voice-activated surgery took place at the UKs North Hampshire Hospital. The operation was performed by a consultant orthopaedic surgeon Neil Thomas to repair the knee of an injured amateur football player. The operation was performed by the surgeon addressing a computerised robot called Hermes,

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which controlled the camera throughout the key-hole surgery.

Hermes is able to recognise over 100 verbal commands and also has the ability to use surgical instruments such as drills, cutters, and suction equipment. Developed by the US Stryker Corporation, the robot makes a 'voice card' for each surgeon that will operate it. It responds to such commands as 'Hermes, connect the camera' by instantly producing a detailed image of, in this case, the inside of the patient's knee. It confirms this has been done by replying 'Camera Connected'.

The system is already well used in the U.S., but has yet to be used as extensively in Europe. It is reported that more than 1,000 operations have been assisted by Hermes in the US in 1999, and it has reduced operating times by an average of 15%. It is claimed that it is more precise than the human hand and consequently may also speed patients recovery.

The Stryker Corporation anticipates that Hermes will be controlled by the voice of a doctor in an entirely different hospital or country. It also points out that it is the first voice-activated programme to pass safety regulations set by the Medical Devices Agency in Britain, because, it says, ordinary commercial systems are too prone to mishear commands. There are already, we are told, 300 'endosuites' in the U.S., in which the surgeon can use his voice to control everything 'from the position of the operating table to his choice of music'.

2. United States

Technology trends report

The Society of Manufacturing Engineers (SME)* of the US have published their '1999 Technology Trends' report' which examines trends up to 2006 and beyond. It provides industry leaders, analysts, and end-users with information that it believes will help them stay current on the latest trends in technology in computer-based manufacturing system. The report was presented by the Computer and Automated Systems Association of the Society of Manufacturing Engineere (CASA/SME).

The report identifies current trends in computer and automated systems, including: manufacturing enterprise leadership; strategic enablers; data communications; product realization; and globalization.

The SME General Manager, Nancy Berg reports that:

> "Industry leaders in the field of computer and automated systems developed the CASA/SME Technology Trends report." "Experience-based end users and academia can use these trends as a key tool to gauge where industry is heading and why. With today's fast pace of change, this report offers manufacturing professionals the necessary tools to increase their knowledge and improve their own businesses."

Contributing more than one-third of the nation's economic growth, Information Technology (IT) industries accounted for only eight percent of the total economic output from 1995–1998. By 2006, almost half of U.S. workers will be employed by industries that produce IT or are intensive users of it. Recruiting, retaining, developing, and motivating people are key issues in maintaining growth in IT industries. The report also identifies ten essential elements of manufacturing enterprise leadership and discusses the importance of strategic alignment for successful long-term competitiveness and business viability. Several trends and events have emerged within the information technology domain, which have both enabled and altered the means in which information is dispersed throughout the manufacturing enterprise. First and foremost has been the onset of e-commerce and the Internet. The report also focuses on the impact of commodities, open source code, and hardware giveaways on the balance of power between manufacturer and customer.

The report addresses some of the key issues currently facing the communications infrastructure. The communications infrastructure is heading toward a mix of dedicated communication links supplemented by virtual private networks, providing bandwidth on demand. Some of the challenges being met are: responding to increasing traffic demands; reducing the cost of participating; providing increased security; increasing availability; and simplifying the man/machine interface.

Considerable pressure exists to advance improvements in the wide range of technologies that influence the product realization process. Specific technology areas covered in the report include: visualization; interfaces between PDM and ERP systems; shop floor control technology; and green manufacturing.

The amount of information that manufacturing professionals must process has increased at a staggering rate. Identifying prevalent technology systems that corporations currently use to manage knowledge, the report also addresses where knowledge management is headed.

SAFETY-CRITICAL SYSTEMS

Anyone involved with automation and robotics will appreciate that a great deal of research needs to be carried out on safety critical systems. A report from the University of Glasgow, Scotland, UK, describes how a team from its Computing Science Department has created a set of principles that can be used to guide the application of formal methods during investigations.

Recently a number of accidents have raised concerns amongst the public about the operation of so-called safety-critical systems. Any new techniques that can be developed to aid accident investigations will be particularly welcomed. If any sort of feedback can be offered to the developers of such systems then we will, perhaps, all benefit.

Safety-critical systems are, by their very nature, difficult to design and are complex in operation. They are also, it would appear, difficult to define and to test, particularly if

* SME, headquartered in Dearborn, Mich., U.S.A., is an international professional society dedicated to serving its members and the manufacturing community through the advancement of professionalism, knowledge, and learning. Founded in 1932, SME has over 60,000 members in 70 countries. The Society also sponsors some 295 chapters, districts and regions, as well as 275 student chapters worldwide.

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software, which is notoriously difficult to prove, is involved. Information about the operation of a safety-critical system that is the subject of an enquiry because of involvement in an accident or incident presents many challenges. Recently as a result of accidents in the UK and in other parts of the world there has been disquiet over the quality of the reports. An article in a Research File of IMPACT (No. 24), a publication of the UK's Engineering and Physical Sciences Research Council confirms this. It says that:

Making sure such appalling events don't reoccur depends on the quality of such reports. However, because of the way reports are currently compiled, complex expert analyses may not accurately reflect the complex interactions that led to major accidents. This can obscure the fundamental causes of an accident, and the failures that threaten safety in one application may remain uncorrected in other systems, with disastrous results.

Indeed, it is perhaps surprising that few techniques can be used to analyse the interaction between system failures and human error during accident investigations.

What the research team at the University of Glasgow has done is to create a set of principles that can be used to guide the application of formal methods during investigations. The team lead by Professor Chris Johnson has developed a range of computer-based tools that can enable their users to produce an overview of the argument in an accident report. The report gives an outline of system:

Most accident reports can now be obtained electronically. The user indicates to the system what the primary conclusions were. The tool then uses information retrieval techniques to find all sections of the report (and any other associated documents) that contain evidence which relates to those conclusions: This automates the careful inspection that is traditionally performed by lawyers during the preparation of a case.

Professor Johnson says that:

"Modern computing resources can cover a far larger set of documents in a fraction of the time than was previously required. My aim is not, however, to support the legal profession but to provide a tool that can be used to check the coherence of an accident report before it is published."

The Glasgow University researchers produced a simplified output from one of its case studies to illustrate how their system would react to it. The case study involved a report provided by the Australian Maritime Investigation Unit. Three levels of output were presented. A top level represented one of the conclusions of the report. A second level indicated the argument of analysis that supports the conclusion. Whilst a final one represents the evidence to support or weaken that argument. This example which is fully illustrated in the IMPACT article, shows how these new techniques identify usability problems in accident reports.

This research group is also using desktop virtual reality techniques to provide accident investigators and the readers of accident reports with the means of what they describe as 'walking through' the events that have led to human error and systems failure. This is an approach that can provide a complete overview of the increasingly complex interactions that cause and exacerbate major accidents and incidents.

Any system that can provide feedback to the designers of our complex safety-critical systems is to be encouraged. Recent accidents have occurred worldwide in areas as diverse as oil production, public order, agriculture, healthcare and public transport (particularly air and rail). The public's concern over the quality of the subsequent enquiries and the reports of the accidents and incidents is growing. So much so that further enquiries are demanded. It is hoped that Glasgow's Computing Science department's new system will set out principles that can be used to guide the application of formal methods during an investigation, and that the research will be a major contribution to the development of safer systems.

Further details on the web link: www.dcs.gla.ac.uk/research/gaag/summary.html

WORLD ROBOTICS – STATISTIC, ANALYSIS AND FORECASTS

Publication of the United Nations and the International Federation of Robotics (IFR)

The publication "World Robotics 1999-Statistics, Market Analysis Forecasts, Case Studies and Profitability of Robot Investments"† is produced by the *United Nations* and co-authored by the *International Federation of Robotics* (IFR). Released at the end of 1999 it contains a wealth of detail about a wide range of information about robotics. It covers the period to 1998 and inclusive forecasts for the period 1999–2002. Some of the highlights of the publication are included here and further details will be included in future 'Reports and Surveys'.

**Sales and Industrial Robots*

Sales of industrial robots are booming in Europe and North America but plummeting in Japan and Asia.

**World market fell by 16% in 1998*

Worldwide sales of industrial robots peaked in 1990, when they reached over 81,000 units. Following the recession in 1991–1993, worldwide sales of industrial robots plummeted to about 54,000 units in 1993. The world robot market then started a period with a sharp recovery which peaked in 1997 when it reached a level of 85,000 units. In 1998, however, sales plummeted by over 16% to 71,000 units (see Table 1 and Figure 1). (Permission granted to reproduce these in *Robotica* by UN/ECE Information Office, Geneva, Switzerland).

† *Further information about the publication: The publication World Robotics 1999 – Statistics, Market Analysis, Forecasts, Case Studies and Profitability of Robot Investments* is available, quoting Sales No. GV.E.99.0.24 or ISBN No. 92-1-101007-1, through the usual United Nations sales agents in various countries or from the United Nations Office at Geneva (see address below), priced at US$ 120: Sales and Marketing Section, United Nations, Palais des Nations, CH-1211 Geneva 10, Switzerland. Phone: (+41 22) 917 26 06/26 12/26 13. Fax: (+41 22) 917 00 27. E-mail: unpubli@unog.ch

**Plummeting sales in Japan and the Republic of Korea*

The large drop in sales between 1990 and 1993/1994 was mainly due to the sharp drop in the supply of robots from Japan, from 60,000 units to under 30,000 units in 1994. It is interesting to note that in 1994 the gross supply of robots in Japan was three times as large as the net increase in stock, indicating that as many as 20,000 robots were taken out of operation.

The sharp fall in sales in 1998 was mainly a result of plummeting sales, not only in Japan, but also in the Republic of Korea. Sales in these two countries fell by 21% and by as much as 75%, respectively, as compared to the 1997 level (see Table 1 and Figure 1).

**World market excluding Japan and the Republic of Korea is growing fast*

When Japan and the Republic of Korea are excluded, the remaining world market shows an impressive increase of 16% in 1998, compared with 1997. This healthy growth rate should also be seen in the light of growth rates of 21% in 1996 and 35% in 1997 (the corresponding growth rates for total world market were only 11% and 7%, respectively).

**United States - a temporary halt in the surge of robot investment in 1998 but skyrocketing sales in the first half of 1999*

After three years of yearly growth rates of the order of 30%, the market in the United States fell by 5% in 1996. In 1997, the market was again booming, showing a growth of 28% over 1996, reaching a record 12,500 units. In 1998, however, sales dropped by 13% in terms of units and by 7% in terms of value (see Table 1 and Figure 1). This was most likely just a temporary setback, since order intake from the American market skyrocketed by 90% in the first half of 1999, compared with 1998.

**Steady growth in the European robot market*

The European robot market increased by 10% in 1998, to about 22,000 units (see Table 1). The order intake in the first half of 1999 increased by 32% over the same period in 1998, indicating that 1999 will see a continued surge in robot investments.

Growth in 1998 was, however, rather unevenly distributed among countries. In the eight smaller western European countries growth was as large as 28% (see Table 1). In

Table I: Yearly installations of industrial robots 1997 and 1998 and projections for 1999 and 2002. Number of units.

Country	1997	1998	1999	2002	% change 98/97
Japan	42.696	33,796	33,800	43,000	− 20.8
United States	12,459	10,857	11,700	15,573	− 12.9
Germany	9,017	9,938	10,500	13,000	10.2
Italy	3,692	4,381	4,950	6,750	18.7
France	1,721	1,653	1,950	2,650	− 4.0
United Kingdom	1,792	1,282	1,800	2,000	− 28.5
Big six	**71,377**	**61,907**	**64,700**	**82,973**	**− 13.3**
Austria	250	250			
Benelux	906	959			5.9
Denmark	130	215			65.4
Finland	220	378			71.8
Norway	67	63			− 6.0
Spain	1,203	1,810			50.5
Sweden	617	691			12.0
Switzerland	289	357			23.5
West-Europe-8	**3,682**	**4,723**	**5,400**	**7,200**	**28.3**
Eastern-Europe	**184**	**206**	**200**	**500**	**12.0**
Australia	526	347			− 34.0
Rep. of Korea	5,759	1,431			− 75.2
Singapore	500	500			
Taiwan, Province of China	753	759			0.8
Asia-4	**7,538**	**3,037**	**3,000**	**4,000**	**− 59.7**
Former USSR	1,000	500	1,000	1,000	− 50.0
Other countries	1,300	800	800	1,200	− 38.5
Grand total	**85,081**	**71,173**	**75,100**	**96,873**	**− 16.3**

Sources: United Nations Economic Commission for Europe (UN/ECE) and International Federation of Robotics (IFR).

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Spain, Denmark and Finland, growth varied between 50% and over 70%.

Among the larger countries, Germany recorded a growth of 10% and Italy 19%. In France sales dropped by 4%, and by as much as 29% in the United Kingdom. This, however, is not unusual for the United Kingdom, which has for years shown a pattern of surging growth every second year and sharp falls in the years in between.

**Asia is a depressed, market - for how long?*
As was shown above, sales plummeted in Japan and the Republic of Korea. In Singapore, Taiwan Province of China, Thailand and other Asian emerging markets, the previously good conditions for robot investment have come to a halt – at least temporarily (see Table 1). In Australia the market fell by 34%.

**The value of the world robot market fell 14% in 1998*
The value of the 1998 world market was estimated at $4.2 billion, down 13% from 1997. Measured in national currencies, the market fell by 48% in the Republic of Korea (measured in US dollars), 33% in the United Kingdom, 14% in Japan and 7% in the United States. In Germany the market value was flat while it increased by 13% in France and 19% in Italy. It should be noted, however, that the robot units only account for about a third of total robot system costs.

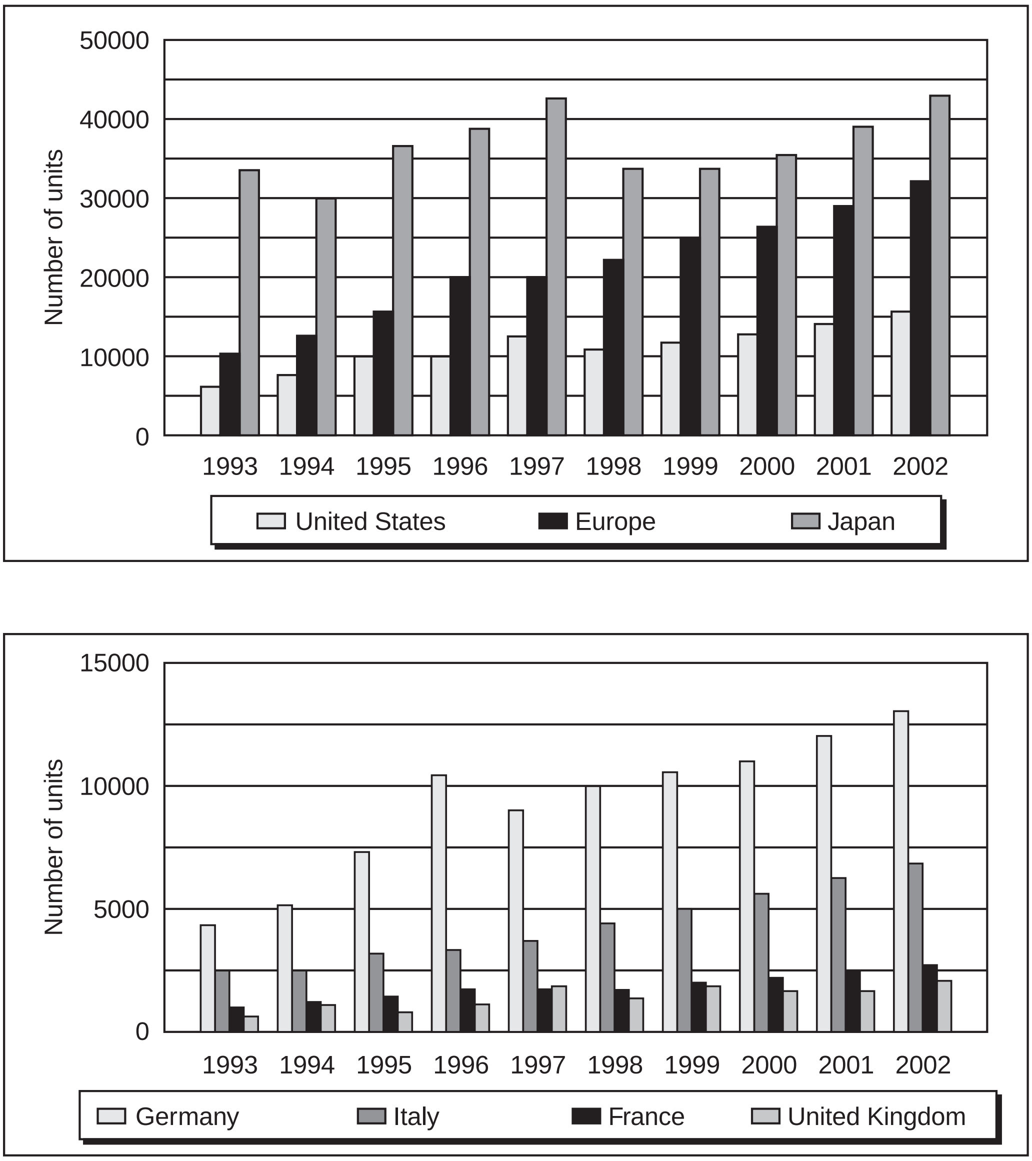

Fig. 1. Yearly installations of industrial robots 1993–1998 and projections 1999–2002. (Note that Europe and United States apply a more srict definition of industrial robot than Japan. Sources: United Nations Economic Commission for Europe (UN/ECE) and International Federation of Robotics (IFR).)

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