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Reports & Surveys

APPLICATIONS OF AUTOMATION & ROBOTICS

1. Robodogs

The American public has greeted the arrival of the Robodog with a great deal of enthusiasm, but not the animal rights lobby. The Robodog is, in fact, an ordinary police dog that has been equipped with latest high tech systems, and is still under the control of a human handler.

The New York Police Department (NYPD) in its fight against crime has harnessed a new weapon which is officially known as *Recon,* which stands for the *R*emote *C*anine *O*ptical *N*avigator. This is the Robodog that is, in fact, one of the Department's dogs dressed up with an infra-red video camera that beams pictures back to the dog's handler. The canine surveillance system consists of a camera on a leather harness that hangs from the dog's neck and a tiny television monitor attached to the handler's bulletproof vest. NYPD spokespersons have already anticipated criticism from the animal rights activists by insisting that it will pull out its robodogs from any potentially dangerous situations. The robodogs will, the head of the NYPD K-9 unit says, soon be fitted with bulletproof vests in the same way as their police handlers. One robodog was used in a recent incident to search for an armed suspect in a Staten Island house and relayed to the waiting police pictures of the basement and first floor interiors. This left only the top floor, and it was concluded the gunman was hiding there. With the dog withdrawn the police were able to storm the top-floor bathroom and found the gunman already shot dead. The all-seeing robodog is set for a useful future not only in police work but in many other applications where canine characteristics can be merged with the latent technology. The canine nose has already been utilised in many situations, so now too, the dog with a sense of smell probably one million times more powerful than the human's will also be matched to the currently develop-high technology. A true robotic dog may yet be developed but until then we will continue to interface with the ordinary kind.

2. Robot clerk

A project funded by the European Union and the resulting collaborative work involving universities and industry has produced the development of a *R*obot for *A*ssisting the *I*ntegration of the *D*isabled, or *Raid,* as it is now known. At the centre of the workstation called *Raid,* is an extended robotic arm with more than 1.5 metres of travel. It can lift up to 4 kg (9 lbs approx.) and can rotate through several axes. By using a pneumatic tool-changer and different heads, *Raid* can cope with a variety of tasks. It can, for example, take paper from trays, place the sheets on a reader board and turn them over, staple them together or put them back in the tray, or, alternatively, put them in a waste bin. For other tasks a general gripper can be used so that it would be capable of handling disks, drinks in glasses or cans and other objects. Even Compact Disks (CDs) can be handled when a suction cup is used. So versatile is *Raid* that the developers say that it can take a book from a shelf of 18 volumes, all of different sizes, put it on a reader board and flip through the book until the required page is found. Not only that, but it can also move and load CD-Roms and floppy disks. Of great importance to the user is the capacity it has to operate any standard PC accessory such as a printer or scanner.

The applications of such a system are of course numerous. In particular, the robotic arm will allow disabled people to become independent, at work and at home. It has already been on trial at the UK's Papworth Hospital, Cambridge where as a £50,000 PC system it was controlled by a joystick on a wheelchair which has a two-way infrared link.

The collaborators in the project were: Cambridge University (UK), Lund University (Sweden), Oxford Intelligent Machines (UK) and Armstrong projects. Already over nine of the workstations are on trial in the UK. France and Sweden. The target group for the system is wheelchair users who have insufficient manipulation capability for operating a computer workstation unaided, but who are able to manipulate a basic input device such as a joystick, click switch or rollarball. A spokesperson for Oxford Intelligent Machines, which holds the manufacturing and distribution rights for *Raid* says that

"the workstation brings together many functions a disabled person cannot perform on his or her own . . . It should allow the user to become independent for a whole day's work . . . It also allows people to be independent at home and perhaps continue with their education or just sit for a few hours listening to music without the need of a helper to turn the page or change a CD."

Apart from its obvious usefulness to disabled people it can assume the role of the clerk to carry out office tasks in particular those related to PCs, as well as many other operations. Perhaps the era of the Robot Clerk has arrived!

3. Automated farming

When automation came to the farm we saw its progress as a natural extension of the industrial applications which had been so successfully implemented. We have reported on automated tractors, robotic gardeners, automated milkers, robotic sheep shearing, and even automatic slaughtering and butchery. Now, however, the meaning of automated farming is beginning to change. The creation of the world's first cloned adult sheep announced in Scotland, UK, in February 1997, paves the way for genetic manipulation of farm animals, more cheaply and accurately. The cloned sheep, a Finn Dorset sheep called Dolly, paves the way to an unprecedented genetic manipulation of farmyard animals. For example, a single cell could be taken from a prize bull, elite racehorse, or award-winning pig and hundreds of identical animals could be automatically produced using the patent cloning technology now available.

It also means that genes could be automatically introduced or deleted in the cloned cells so that animals could be 'manufactured' to produce drugs in their milk or to grow faster for meat production. Resistance to disease could also be built into the process. The researchers are, of course, new and it will take some years before scientists will deliver the means to change so many genes simultaneously. Such automation on the farm does bring its risks and its limitations; its use could, for example, produce herds of identical livestock and consequently, be at greater risk of disease.

Animal breeding companies are already showing interest in the use of this technology to multiply their best animals. Genetic modifications of the donor cells in culture before they are used in the process will allow the precise introduction of changes in their DNA. This opens up the opportunities for a range of new products. Healthcare products are but one example. The farm is therefore becoming a factory that produces not only foodstuffs but other much needed medical products that could revolutionise the treatment of diseases.

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4. Smart technology aids disabled
Scientists at the University of Reading UK have been active in developing devices and systems which will help disabled or elderly people. The current major systems and projects include work on 'smart house' technology for purpose designed housing, a sensor-aided intelligent wheelchair and developing navigational systems to help disabled people negotiate public buildings.

The First European Conference of Disability, Virtual Reality and Associated Technologies was held in Maidenhead, Berks. (UK) in July 1996. It was supported not only by the University of Reading but also by the IEE, BT (British Telecom) among others. Called *ECDVRAT* (*E*uropean *C*onference on *D*isability. *V*irtual *R*eality and *A*ssociated *T*echnologies) it enabled a variety of participants to meet and discuss the state of the art of the associated technologies and their relevance to the conference theme. Presentations included those of academics, from industry and from the disability groups and individuals. They were all required to demonstrate clearly the applicability of virtual reality research, and the organisers adopted a very broad interpretation of virtual reality (VR). This was so that it could alllow associated technologies to be included. A wide range of topics were presented and discussed and they form the basis for on-going research and development. They ranged from how VR might be used to enhance functional recovery following brain damage to a virtual keyboard based on eye tracking.

Further information about *ECDVRAT* and the research and development activities can be obtained from the Department of Cybernetics, The University of Reading, Reading, Berkshire (U.K.).

COMPUTER WITH HUMAN TRAITS?

There is always a great deal of scepticism shown to scientists who announce they have developed devices that have 'human-like' characteristics. There have been so many false claims that we are now wary of those who claim their systems not only have ordinary human-like qualities but also a 'will' or 'intelligence'.

A development team from the University of London's Imperial College (UK) unveiled such a system at the British Science Museum in December 1996. The team claims that the powerful piece of computer technology on display demonstrated human traits. Called *Magnus,* they insist, it has a mind of its own. It looks not much more than an ordinary laptop computer, and its developers say that the technology inside allows it to demonstrate many of the elements of consciousness. They claim it is conscious of its surroundings and its existence and show signs of being able to exercise freewill.

The researchers say that *Magnus* was designed to revolutionise understanding of the workings of the human brain. They believe it is a step forward in the field of computer science which is involved with neural networks. These neural systems, as most readers will know, make computers respond as if they consisted of a collection of brain cells, that is neurons, which are linked together. They are, of course, not programmed like conventional computing machines but trained by example and acquire their expertise in many ways similar to the human's brain. This gives them the power to tackle problems which were not previously addressed.

The Imperial College research team leader, Professor Aleksander said at the launch of *Magnus* that:

"We wanted to investigate consciousness by building a machine based on guesses about how real brains might produce it. But real brains are too complicated to use and you cannot easily see what is going on inside them. With a machine you can."

The project has already cost some £500,000 so far, and it is hoped that it will lead to the development of computers that are far easier for humans to work with. Professor Aleksander and his team do, however, have their critics. Several neuroscientists do not believe that what has been created is anything like consciousness. The debate on what is meant by consciousness and whether computing machines can be built to achieve it is a familiar one and is, currently one that is occupying the minds of some of the world's most profound thinkers.

To help us understand what *Magnus* is capable of, and, indeed to provide food for the debate, the researchers claim that:

- *Magnus* can link objects to their names, learning the meaning of words, when let loose in simulated 'worlds'.
- It also shows signs of understanding the results of its actions after exploring these worlds and learning about the effect it can have on them. This, it is believed, suggests an awareness of its own existence.
- *Magnus* has been given a sense of hunger, and, its creators say, can select a piece of fruit when it feels hungry, thus deducing for itself the best course of action.
- *Magnus* can, in a given situation, show awareness of the many possible actions it can take, and is capable of choosing the best one for a specific purpose. This, its creators say, shows an ability to exercise free will.

Professor Igor Aleksander has already produced a book – *Impossible Minds* (Imperial College Press, 1996) where he discusses many of these controversial issues. Sir Roger Penrose in his books: *the Emperor's New Mind,* and also *Shadows of the Mind,* has examined in some depth the issues involving conscious machines and our understanding of the mind. Other books and scientific papers continue to be published about this fascinating topic. The arguments have been stated simply by some scientists: Can computers be made that are as smart as we are? Can, for example, computing devices capture human mathematical understanding? These issues have also recently been discussed by Highfield and Coveney, in their book *Frontiers of Complexity* (Faber, London, paperback, 1996).

EUREKA PROGRAMMER PROPOSALS

Recent proposals for the EUREKA programme have been published. They are made to the European Community's EUREKA programme – which was created in 1985 to strengthen the global competitiveness of the European industry by promoting Euro-wide co-operative research and development. Some 24 European countries and the European Union are now members. Each EUREKA project involves partners from at least two Member Countries and aims at developing advanced civilian products, processes or services for the world market. More information about these programme summaries can be obtained by calling the EUREKA Enquiry Point (UK 0171 215 1618. For other European Countries, call: EUREKA Secretariat for their contract numbers, at +32 2 229 22 40, fax: +32 2 218 79 06, e-mail: kirsten.voje@es.eureka.be). The proposals include:

- *Factory Guideline* (EU1626) – to create 'dynamic guidelines' for SMES to help them improve their overall capabilities and general business strategies and adapt to an ever changing environment. The guidelines will be backed by a web site, CD-Rom. (Helsinki University, Finland – Jussi Kanerva)
- *Factory Timeshare* (EU1629) – to create a team-driven management system using multi-based communication strategies for sharing information between engineering, production operations and the customer. (CIMulation Centre, UK – Michael Douglas)
- *DIIN* (EU 1630) – to research and develop prototype software for interior design programs, using photorealistic virtual reality images and designed to run on standard desktop personal computers. (Logical Software, SA Spain – Marc Leclerc)
- *MULTIMEDIA VISUALWEB* (EU1633) – developing software for the internet containing information in

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geographic and multimedia forms. The software to be connected to a database allowing, the web browser total interactivity (Visual Gis, Spain – F. Javier Bernandos)

- *Y2K System* (EU1851) – to research and develop a solution to the catastrophic program failures for the turn of the century, when due to a date problem, most mainframe computers will crash. (Y2K Solution, The Netherlands – Han Van Doorn).
- *HEROIC* (EU1665) – to research and develop real-time operating systems technology and supporting software for embedded Internet devices. To include a body movement tracking system for virtual reality applications. (Perihelion Distributed Software Ltd, U.K. – Jonathan Powell)
- *LAND 3D* (EU1670) – an innovative authoring software that will allow the programmer to create CD-Roms visually, and the user to walk virtually in three dimensions (Strass, France – Anne Marleix)
- *BEN* (EU1632) – the development of an artificial nose to detect explosives, drugs and environmental contaminants based on biosensor technology, micromechanics and microelectronics. The nose to have a fast response time and sensitivity equal to that of a trained dog and can be installed or hand-held for field use. (Bofors Applied Technologies AB, Sweden – Sten-Anders Brink)
- *SPECTRAKAR* (EU1668) – to develop a new range of genetic diagnostic tools that will enable large numbers of genes to be visualised on the simultaneous multicolour analysis of fluorescence stained cells and chromosomes. (Applied Imaging International, UK – Leslie Grant)

ANACARD (EU1691) – to develop a general hardware platform for measuring and analysis acoustic and electrical signals generated by the human body. The platform to be configured to specific diseases and applications by applying software modules. (Bang & Olufsen Technology, Denmark – Jan Simonsen)

- *NATHES* (EU1669) – a real-time study of an automated system for the protection of the environment and for the security of people and goods in and around sites where there are technological risks, such as chemical, oil and nuclear industries. (Compagnie des Signaux Systèmes de Securité/Icare, France – Michel Di-Russo)
- *SIRENET* (EU1640) – research and new developing into a new generation of software tools for simulation, planning and management of communication networks. (SGT SA, Spain – Jose Vicente Rodriguez)
- *ROBVAG* (EU1646) – combining multi-axis robot technology with fibre optically-based diode pumped Nd-YAG laser welding to improve planning, performance and control of the weld process. Application in robotics and production automation. (OSS, Denmark – Michael Sellerup)
- *MSO-CNC* (EU1649) – improvement project in robotics and automation to improve the quality of machine tools by development of a lathe which uses a high speed spindle and with a control unit to allow the creation of CNC programs (Lernstatt, Czech Republic – Peter Valclavik)
- *LOCBUS* (S8153) – a project suggestion for the development of a unique Automatic Vehicle Location and Control System, including vehicle location, and information, links between vehicles. (Era Traico, Spain – Hector Corzini)
- *FACTORY MANAGEMENT* (S8164) – the development and implementation of a factory management system that effectively solves the problems arising at the different levels of a decision-making hierarchy. These would include lotsizing, inventory control, scheduling of an integrated man, machine and materials handling system. (Bilkent University, Turkey – Ihsan Sabuncuoglu)

MAGNETIC LEVITATION

Professor Eric Laithwaite, who was the Professor of Electrical Engineering at the Imperial College, London UK, has been promoting the potential of 'magnetic levitation' since 1947. Now the *US Space Agency* at NASA has recognised his idea. His concept, that trains can run held above a track on a magnetic field, is now set to be used to develop a cheaper way of launching rockets.

Professor Laithwaite is now part of an advisory team that is developing a plan to launch spacecraft via a five-mile magnetic levitation track built inside a 10,000 ft. mountain. The system being developed is the mainspring of a new multi-billion dollar project and has been given the name *Maglifter.* They claim that if successful it will not only save billions of dollars in space launches but will also prove to be more environmentally friendly.

The design by Professor Laithwaite relies on magnets which are powerful enough to raise the launcher above the tracks. The space craft rests on a ledge, which is pushed along the track using the power of electro magnets. Obviously, because it is resting on air there is little friction to over-come and it is able to accelerate smoothly up the 45 degree incline until it emerges from the tunnel at 600 mph, the speed required to go into orbit. At this point the rocket separates from the sledge and continues its journey into space. This has been described in Nasa's report of the project which highlights its goals:

- The rocket to be fired is put on to the launch sledge which is only to be levitated a few centimetres above the track.
- The rocket and *Magley* (magnetic levitation acceleration sledge) to be designed to be magnetically accelerated along a frictionless track to 600 mph.
- The *Maglifter* Tunnel to be five miles long with elliptical crossection with axes 40 ft vertically and 60 ft horizontally. Constructed of reinforced concrete and with a pressurised launch shaft rising to 10,000 ft at 45° angle.
- Launch facility starts ignition sequence of the rocket motor before launch vehicle leaves tunnel, boosting the rocket into space.
- *Magley* sledge to be recoverable for next launch.
- Launch cost to 600 mph estimated to be £1,000.

Professor Laithwaite sums up the advantages of the system by claiming that:

"... there will be huge savings on fuel. In the normal launch it takes huge quantities of fuel – sometimes two-thirds of the weight of the whole rocket – to get to 600 mph. This system will get it to that stage for about £1,000. Also, the launch track can be used again so even allowing for the initial investment it will be cheaper in the long term and more environmentally friendly ..."

The recognition of the British inventor's idea that has been ignored by British industry for 50 years, does give encouragement to others who were similarly treated.

RESEARCH APPLICATIONS FROM THE NEUROSCIENCES

Recent reports from the Engineering and Physical Sciences Research Council (EPSRC) in the U.K. pinpoint projects in the neurosciences that have received their support. Many of these projects have application in several fields including robotics and automation. Summaries of the work in three areas are included here, together with Internet Web and Email links:

1. New communication aids

The Department of Electrical and Electronic Engineering at the UK's Imperial College, London University, and the Royal Hospital of Neurodisability have collaborated on an EPSRC project which, it is believed, could provide important new communication aids for people with severe brain and other disabilities. The *Brain–Computer Interface* (ECI) project is developing machine learning techniques around ANNs to help interpret signals from the brain's motor cortex which are recorded by electroencephalography (EEG). The report to the EPSRC says that the ECI project is focusing on changes in brain activity that precedes a physical action, such as moving a

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finger. Initial experiments, the researchers say, using able-bodied subjects, have shown that its technique can detect such 'movement planning' even when the action itself does not then occur. Dr Maria-Stokes, who is the Director of Research at the Royal Hospital says that:

"These early results suggest this is one of the most promising approaches to establishing awareness in patients with very severe brain injury who cannot make any physical movements." "Provided firm assurances can be given about the consistency and reliability of analyses that detect conscious awareness, BCI could provide a valuable additional aid."

A key technical challenge to the Imperial College team of Drs. Stephen Roberts, William Penny and Phillipe de Wilde has been to ensure that decisions and information produced by computer analysis are accurate. Dr Roberts reports that:

"We had to find a fresh approach to evaluating confidence measures for decisions made with ANN models. This has involved using statistical methods to calculate a confidence estimate for each analysis. Results with a poor confidence level can be rejected. Greater confidence can be built using clearer information, say from a previous analysis."

"We have sought to preserve simplicity in the computation required as this improves the performance with new data that had not been used in training the ANN model."

It would appear that finding the appearance of coherent 'synchronised' rhythms in an EEG area of critical significance to the analyses. These represent tiny EEG voltage changes embedded in much larger background electrical activity, so that information presented to models must be carefully filtered and pre-processed.

It should be noted that the ECI project has ethical medical clearance to take recordings from brain-damaged patients at the Royal Hospital, starting this year. These are made using electrodes placed on the scalp and communication is attempted via usual and auditory stimuli.

Future objectives of the ECI project are to use the brain-signal analyses to interface directly with a computer. This will, of course, lead to the possibility of controlling devices. One current suggestion for example is the control, eventually, of a wheelchair.

Contact with the research team of the BCI Project can be made through the Web Link:
httpc://www.ee.ic.ac.uk/research/neural.bci.html.

2. Modelling brain mechanisms

Research led by Professor Mike Denham at the Centre for Neural and Adaptive Systems (CNAS) at the UK's Plymouth University School of Computing, explores new computing architectures that draw on advances in brain modelling. This EPSRC-funded research is summed up in a report which says that:

"... researchers at the CNAS are applying the latest neuroscience knowledge about the workings of the brain to develop computer systems which learn from experience. A key aspect of this is the way the brain forms new goals in response to what it learns from its sensory experiences, without the need for any external intervention."

The EPSRC report says that both Professor Denham and Dr. Susan McCabe have developed a model of the interactions between different brain regions in the dynamics of learning and goal-directed tasks. The researchers at CNAS are also focusing on modelling brain mechanisms used in dealing with sensory perceptions and in particular about how this is integrated with other learning and memory processes. For example, the report says:

"Dr McCabe has drawn on neuroscience and psychological studies to build a model of how the brain picks out and makes sense of individual sounds from a background of multiple auditory signals. The model performs auditory 'streaming' using incoming signals and traces of previous activity as feedback to influence subsequent signal processing. Its behaviour matches a number of well known psychophysical results."

CNAS research also includes the following:

- Dr Guido Bugmann's investigations in the detailed dynamics of activity within networks of biological neurons and the development of models of spatial navigation for mobile robots.
- Cooperative exploration and learning behaviour of multiple autonomous agents such as systems of neural networks.
- Potential applications that include speech recognisers, mobile robots, modelling aids for understanding brain disorders and intelligent Internet information filters.

More details of the CNAS research activity and projects are on the WEB Link:

http://www.tech.plym.ac.uk/soc/research/neural/index.html.

3. Smarter sensors – learning from nature

There is little doubt that we are still learning from nature. We are told, for example, that while hovering, the large dragonfly holds its station with great precision by detecting small movements of the image formed by its exceptionally large compound eyes. Research at Cambridge University UK, into the way creatures detect movement is providing valuable practical understanding to help build more adaptable and efficient photosensitive devices and microchips for motion detection. Insect's eyes, it would seem, make such smarter sensors and research has been directed towards investigating how different insects react to the same visual stimuli.

Research reported to the UK's Engineering and Physical Sciences Research Council (EPSRC) indicate that Drs. Simon Laughlin, David O'Carroll and John Daugman of Cambridge's Zoology Department have made important advances in their study. This involves knowledge about the design of neural networks responsible for coding and processing moving images. Dr Laughlin says that:

"The exceptional facilities offered by the modular construction and simpler organisation of insects' compound eyes are an invaluable aid in determining the operating principles underlying visual systems."

The Cambridge group have a EPSRC project which is concerned with comparisons of the neural responses in the visual systems of ten insects, chosen for their different habitats and patterns of behaviour. To do this, they developed a new experimental approach for rapidly and accurately analysing sensitivity to movements by measuring responses to computer-generated patterns.

It is believed that the study has accumulated some of the most detailed information ever gathered on how neurons respond and adapt to visual motion. They found, for example, that neural circuits in fast aerobatic flying insects like bumblebees, are tuned to detect very rapid movements, while those in hovering insects, such as hawkmoths, are honed to detect slower movements. The hoverfly's exploitation of two parallel sets of neural mechanisms to enable it to both hover and make sudden quick movements also offers an insight into potential architectures for smart 'artificial eyes'.

The reports to the EPSRC say that the group's results could also be applied to develop ANNs and VLSI devices which adapt automatically to operate at maximum efficiency as conditions change, say by learning from the way nocturnal insects optimise the use of available light.

Dr Laughlin also observes that:

"This kind of knowledge is very important in understanding how neural networks are structured and adaption takes place. It could also greatly extend the range of applications in which automatic sensors based on ANNs can be applied reliably."

The Cambridge research team reports that they are planning future studies of computer models of motion detection and

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neural netowrks that extract data on shape and position from moving images. Work has also started, the team say, on the measurement of power consumption in the insect visual system, with a view to constructing energy efficient systems.

In addition to the EPSRC project related research by the group it has also been sponsored by the Biotechnology and Biological Sciences Research Council. The research has also included collaboration with the *University of Lund* in Sweden and also the Sussex Centre for Neuroscience, whose researches have also, been reported in this section.

Contact with the research team can be made through Dr Simon Laughlin on:
email:SL104@cam.ac.uk

ROBOTICS AND AUTOMATION WORLDWIDE

1. Australia

The council of the Australian Robot Association (ARA) recommended that the Association's name be changed to: Australian Robot and Automation Association (ARAA). In its *Newsletter* Number 50,1996, the Association stated that other International Federation of Robotics (IFR) member associations have reached similar conclusions about their titles. The Associación Española de Robótica, for instance, is to 'promote the development of robotics and advanced industrial automation in Spain'. It was also stated that the Singapore Industrial Automation Association some years ago dropped 'robotics' from its name. The same *Newsletter* also contained a Table of the interests of all organisational and individual members. This makes interesting reading and gives a good picture of the balance of technological interests in the field in Australia. The data listed in Table I recorded the members' interests, including the number of members expressing interest in each topic. In the table that follows it should be noted that many members indicated multiple interests:

Table I—ARA Interests

Applications to manufacturing	34
Non-manufacturing applications (service, construction, agriculture, health)	27
Machine vision and sensors/peripherals	36
R & D of new technology	43
Education and training	25
Managing a robot installation	7
Investigating potential robot use in my organisation	2
Operations research aspects	1

The ARA is now on the World Wide Web as a trial site and is located at the URL address: http://www.cs.uow.edu.au/isase/ara/. Many other members of the IRA have a presence on the Web and can be accessed for information. One other important item of news from Australia is that the government has ended robot bounty and reduced income tax concessions for R & D expenditure. The Industry Commission has recommended continued duty-free entry of robots. In its submission to the Industry Commission the ARA argued that the robot bounty should be retained and extended.

2. Singapore

Last year Singapore became the first country, it was claimed, to attempt to use technology to stop its citizens viewing violent and pornographic material on the Internet. From the Autumn of 1996 it became the law that the estimated 120,000 Internet users in Singapore must adjust their software so that requests for images and text from the global computer network are routed via government-controlled computers known as 'proxy servers'. Failure to comply with this procedure leads to prosecution and a heavy fine. The 'censoring' system put in place by the proxy-servers contains a limited database of frequently accessed 'approved' material and will check every Internet site a subscriber tries to access against the government's list of banned sites. If a site is banned the proxy server will deny access. Singapore's Information Minister Mr George has already called the move to censor, an 'anti-pollution measure in cyberspace'.

The new system comes as an example to other countries which have expressed a desire to curb access to certain sites but have lacked either the technology or the will to do so, or perhaps, both.

The mechanics of the ban on certain sites are interesting in their concept. The new system is controlled by a panel of 19 members headed by the Dean of the Faculty of Science at the *National University*. Singapore has always been ahead in its computer projects so it is not surprising to learn that it has one of the fastest-growing populations of Internet subscribers. In the last year, the Information Ministry say, the number of subscribers has grown sixfold to one in 25 of the island's three million population. Whilst the new system has already been criticised as unworkable in the long term and criticised on political grounds, it is an attempt to curb the increasing number of sites that contain nudity or sexual content.

The real problem, however, is one which Internet providers and users have recognised worldwide. With present restrictive measures users experience delays and someone will need to finance the longer access times. This delay is likely to increase as the banned site list, currently around a 100, becomes longer.

3. United Kingdom

Automating vehicle identification. Traffic in the United Kingdom, as in most other parts of the world, has become so heavy that controls have to be instituted. Automated systems are therefore appearing in most cities and urban areas. In the UK there are now roadside systems that are capable of differentiating between vehicles for a number of different reasons and purposes. What is needed, we are told, is a system that can pinpoint any information relevant to some pre-formed structure plan. For example, to control a motorway lane that should only be accessed by lorries, or in the cities, to ensure that bus lanes are only used by buses or other designated vehicles. One new system that is due to be operational in London UK, in 1997, is a system that is capable of sorting out cars from buses. In London some car drivers use bus lanes illegally. The lanes were setup to encourage the use of public transport and, also, in some instances to help traffic flow. A new system has been designed to enforce their use. It consists of cameras which use the latest digital video storage and transmission equipment (DVST) developed and tested by the Manchester, UK, company Dedicated Micros. The equipment uses digital images stored on a hard drive rather than continuous tape and the cameras are said to be 'tamper proof'.

Initiative to tackle fraud. A new UK initiative to tackle fraud in corporate life has been launched. The audit faculty of the Institute of Chartered Accountants has proposed a new fraud advisory panel. The new panel will act mainly as a clearing house for all the information, statistics and help that is already available. There is apparently, no shortage of experts or data, but there is no coordination of the knowledge dispersed around a proliferation of authorities. Many different ways of defrauding companies are listed, but the hardest to detect is computer-based crime. The audit faculty says that fear of computer-dependent fraud has been consistently greater than its commission, unless, that is, the theft is so skilled that nobody has detected the removal of the money.

Computer hackers, especially those in Eastern Europe are getting increasingly sophisticated the report says. It is now policy to attempt to stay ahead of them.

4. United States

A report from Pittsburgh, USA, forecasts the building of a Robo City set around the NASA-funded Robotics Engineering Consortium's new headquarters. It is claimed to be the only centre in the world devoted to turning robotic ideas into useful

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machines for real companies. The Director of research for the consortium's virtual reality laboratory, believes that what is being started at the site is the third industrial revolution. He also points out that he believed that the second industrial revolution was the rise of the steel industry, also centered on Pittsburgh.

The centre's researchers expect that companies such as Boeing, Caterpillar and Ford, which are already paying for the first robots, and other spin-off corporations will take over the vacant sites near at hand.

One of the first projects is a harvester for New Holland, North America Inc., using space robotics developed by NASA and Carnegie Mellon University in the last decade. This computer-driven machine uses the satellite-based Global Positioning System, wheel sensors and a video camera to 'see' a crop line, so it can harvest a field without a driver. The machine is also designed to make intelligent decisions on its own. For example, a farmer in another area could even use a cellular telephone to order it to start harvesting. Researchers have used the machine in farm trials and now claim it to be faster and more responsive than a human driver can be. It does, however, come equipped with a cab so that it can be driven by the farmers themselves. The currently quoted price in the US is less than $70,000.

5. Robot costs

Now that robots are regarded as virtually essential to production lines, to scientific research, nuclear safety, antiterrorist systems and to many more application areas that are increasing by the day, their current costs become more than a matter of interest. For example, the costs of some recent models of modern robots are given below, but, of course, they are merely indications of price, since, obviously, such robotic devices normally reside within a sophisticated environment which has to be carefully planned and costed:

- *Robug III* – Estimated cost of $1.3 million. The Robug is designed as a nuclear disaster rescuer by scientists in the wake of Chernobyl. It has eight spidery legs and suction-padded feet, allowing it to climb vertically. A human operator controls its movement via a TV screen.
- *Andros Mark VI-A* – Costed, for the basic model, at $70,000. This is a hazardous-duty robot that can climb stairs at a 45° angle and make 180° turns. It can carry two TV monitors and open fire on targets with a mounted shotgun. Its 17 inch-to-19 in width allows it to get into tight spots.
- *RMI-9* – Starts at $50,000, increasing in cost depending on equipment fitted. It is a Canadian-designed 'remote mobile investigator' which has handled explosive devices, hazardous chemicals and radioactive materials. It is equipped with a semiautomatic shotgun and carries front and rear cameras.

These are some of the robot systems available, which may appear to be unusual in their potential application. There are, of course, many more that perform similar functions and many thousands more designed to function in more conventional roles that are the backbone of the world's modern, automated industries.

6. Robo sapiens

Recent media coverage in the United Kingdom has created a new robot class – *Robo Sapiens.* This highlights, yet again, the advances in robotics, and raises many questions about the robot role in human society. All the usual statements about robots being efficient workers who 'don't get bored, don't ask questions, don't ask for a pay rise, and don't want your job', are repeated. But what is new? Innovative researches have produced prototype devices which, we are asked to believe, show human traits and a degree of intelligence, which however low at the moment, is predicted to rise to a level comparable to that of humans. The result is that when challenged the human race worries about its superiority not only over other creatures but created machines. Some of the newly created robo machines that are said to be getting too clever for *homo sapiens*, include:

- *Robodoc* – a machine that prepares the cavity in the human thigh bone for hip replacement surgery. It is currently undergoing clinical trials in Europe and the US. The human surgeon has to worry when a spokesperson for Carnegie Mellon University's Robotics Institute, Pennsylvania, US., says that "the robots are extremely accurate; they're fast and they can cancel tremors in a surgeon's hand".
- *Robotuna* – this is part of a programme to develop autonomous underwater vehicles to find sources of pollution. Developed at the Massachusetts Institute of Technology (US), this robot is permanently attached to the laboratory, but work on *Robopike,* a free swimming version is a current project. The developers believe that all kinds of robotic creatures will explore the oceans and send back information. They suggest that there could be a *Robolobster* sifting through the sand looking for gold; Robopikes swimming around a reef monitoring the coral and Robotunas looking for vents.
- *Robotic warehouse security guard* – a research team at the University of East London, UK have bulit such a robot guard and called it Victoria. It is a fleshless six-foot metal skeleton with piercing red pupils. Martin Smith of the University says that it has two cameras for eyes and two lasers to give it the ability for range finding. It also has infrared detectors and a small radar to detect humans. This is, for the moment at least, a robot that is programmed to do what it is programmed to do.
- *Robots with the capacity to learn* – at the Cybernetics Department of the University of Reading UK, Professor Kevin Warwick, a world authority on robotic research says that: "... within the next few decades research into artificial intelligence will create computerised robots that could outperform humans in every intellectual capacity.

In his laboratory at Reading and at other centres in the United States and in Japan, he says, advances in computers are already laying the foundation for 'new life forms' that could take control of the planet. In a recent interview he is reported as saying that: "... it is because of our intelligence that we are in the driving seat on Earth ... When machines become more intelligent, so they will take over control."

It has been claimed recently that Professor Warwick was the first scientist in the world to succeed in getting one robot to program another over the Internet. At that time he explained that this experiment showed that machines can learn, like humans, by communicating what they themselves have learnt. He and his research team at the Cybernetics Department are already well known for the miniature robots that they have created. These robots are able to learn from one another and even exhibit new behaviour. For example, the behaviour they exhibited, such as the robots 'flocking' around a leader, had not been programmed into their circuits. Descriptions of the activities of these robots, called the 'seven dwarfs', have appeared in this section. Professor Warwick says that he intends to continue to warn the world about what is happening, but does not in any way wish to 'overreact' by calling a halt to robotic research.

- *Virtual Robot* – *Gandolf* is being developed at M.I.T. to detect body language and gesture. This research is directed at studying the interaction with intelligent robots. When someone in a wired jacket and wearing a virtual reality headset waves a hand at Gandolf, the robot interprets the action as a signal that he/she wishes to talk, and becomes silent. The MIT researchers say that this reaction is not programmed and not learnt automatically either. Based on the reports of progress in the development of robots with the characteristics described here, there seems little doubt that the *Robo Sapiens* are coming. Whether it will mean a world dominated by robots, as illustrated in the best science fiction, or a society of mutual and tolerant co-existence comes into being, is still a matter of conjecture. Scientists do, however, have a responsibility to warn about the possible future scenarios in a world where robots, whatever their degree of intelligence or consciousness, will play a crucial role.

WORLD INDUSTRIAL ROBOTS – STATISTICAL DATA TO 1998

1. Key data for the world market

According to the new annual publication entitled 'World Industrial Robots 1996', prepared by the United Nations Economic Commission for Europe (UN/ECE)* and the International Federation of Robotics (LFR)**, investment in robotics surged by 26% in 1995. It also forecasts that in the period 1996–99, growth will be at 15% per year.

The key data for the world market for 1995 was:

- 75,500 units, 26% over 1994
- $5.7 billion, 33% over 1994
- Breakdown of the world robot market: Japan $2.5 billion (+36%), USA a record $900 million (+30%), Germany, Italy, France and United Kingdom together $1 billion (+36%).
- Average price of a robot unit was $82,000, compared with $108,000 in 1991 (includes only robot unit which on average makes up 30% of total system costs.)
- Three of the largest robot producers accounted for over 30% of the total market.
- The total stock of operational industrial robots is estimated at 650,000 units, +6% over the 1994 stock.
- Japan accounted for almost 60% of the stock, while the USA made up 10% and Germany, Italy, France and the United Kingdom for 15%.

2. Worldwide sales of industrial robots 1990–1995

The worldwide sales on industrial robots peaked in 1990, when they reached almost 81,000 units. After the recession in 1991–1993, sales of robots plummeted to about 56,000 units in 1993. The world market recovered slightly in 1994 with sales of about 60,000 units. A more solid recovery came in 1995 when the market surged by 26% over 1994, reaching 76,500 units.

3. World industrial robots

The large drop in sales between 1990 and 1994 is mainly explained by the sharp fall in the supply of robots in Japan, from 60,000 units to under 30,000 units. In 1995, the Japanese robot market started to recover. Some 36,500 new robots were installed, representing an increase of 23% over 1994. It is interesting to note that as many as two thirds of the robots supplied in 1995 were replacement investment.

As a result of the economic recovery, which in North America and the United Kingdom started already in 1992 but only in late 1993 in western Europe, 1994 was, with the notable exception of Japan and Italy, a booming year for robotics with record sales in many countries. In Sweden, for instance, sales in 1994 were 157% higher than in 1993. In the United Kingdom, the increase was 84%. In the United States, sales surged by 33% in 1993 and by 26% in 1994, which was a record year with 7,600 robots sold. In Germany and France, sales surged by the order of 20%.

With the exception of the United Kingdom this surge in sales continued in 1995. The market in the United States grew by 34%, the third consecutive year with growth exceeding 25%. Germany experienced growth of an impressive 43%, Italy with 30% and France with 16%. The only disappointment was the United Kingdom which saw its market fall by 27%. However, this should be seen in the light of the fact that 1994 was an exceptionally good year for robotics and that the 1995 supply figure after all was the third highest ever recorded.

For the eight smaller western European economies, sales increased by a modest 11% in 1995, compared with a staggering 41% in 1994. This sharp drop in growth was mainly caused by Sweden which saw its 1995 sales fall by 29% compared with 1994, which, however, should, just as was in the case of the United Kingdom, be seen in the light of the fact that 1994 was an exceptionally good year for robotics with, as was mentioned above, growth of a record 157%. Finland and Spain compensated this disappointing result of Sweden by recording impressive growth rates of 62% and 53%, respectively.

The robot market in eastern Europe was almost flat in 1995 compared with 1994. The four Australasian countries Australia, Republic of Korea, Singapore and Taiwan province of China obtained a combined growth of 20%: almost 40% in Australia and the Republic of Korea and 10% in Taiwan province of China. As concerns the Republic of Korea, it should be noted that in 1995 it had become the world's fourth largest market.

4. Estimate of the worldwide operational stock of industrial robots

Since industrial robots started to be introduced in industry at the end of the 1960s, total accumulated yearly sales amounted, at the end of 1995, to some 790,000 units. many of the early robots have by now been taken out of service. The stock of industrial robots in actual operation is therefore lower. ECE and IFR estimate the total worldwide stock of operational industrial robots at the end of 1995 at just under 650,000 units compared with about 610,000 units at the end of 1994, representing an increase of 6% over 1994.

5. Estimate of the value of the world robot market in 1990–1995

In 1990, the world market can be estimated at $7.4 billion. In the trough year of 1993, the world market had fallen to $3.7 billion. It increased slightly to $4.3 billion in 1994. In 1995, the world market surged to some $5.7 billion.

6. Degree of concentration in the robot industry

In the 1980s the robots industry was dominated by a large number of small firms. Through acquisitions, mergers and bankruptcy the number of firms has been significantly reduced. In 1995, three of the world's largest robot producers had combined sales of about $1.85 billion, which represented about 33% of total world sales of robots. In 1990, the same firms accounted for only some 7% of total world sales.

7. Analysis of the development of robot density in selected countries

Japan has by far the highest density of advanced robots. In 1995, it amounted to 210 units (252 when counting all types of robots) per 10,000 persons engaged in manufacturing industries. Sweden had the record highest density with 54 units, followed by Germany with 52, Republic of Korea with 51 and Italy with 41 units. In the other countries in western Europe, Australia and the United States, the density ranged between

* *World Industrial Robots – Statistics 1983–1994 and Forecasts to 1998*, Sales No. GV.E.96.0.26, New York and Geneva 1995. United Nations Sales Section, Palais des Nations, CH 1211 Geneva 10, Switzerland. Price $120. Details of the *United Nations Economic Reports for 1995* were included in Reports and Surveys, *Robotica* **Volume 14,** pp. 247–250 (1996) and they provide valuable background information for the current report.

** Abridged statistics were also discussed in the *IFR News, Robotica* **Volume 14,** part 6, p. 705 (1996) and **Volume 15,** part 1, p. 129 (1997).

about 15 and just under 40. The countries in central and eastern Europe had densities in the range of 2–5.

The development of robot densities is based on all types of robots, in the period 1981–1995 for selected countries. If the densities had been defined as numbers of robots per 10,000 production workers, they would have been at least twice as high as those presented above.

8. The supply of industrial robots in 1995 by major application areas

In most robot-using countries, welding is the predominant application area, particularly if it concerns major motor vehicle producing countries. Of total 1995 new robot installations, the highest shares for welding were: Hungary 73%, United States 52%, Spain 48%, Australia 47%, United Kingdom 46%, Taiwan province of China 45%, Republic of Korea 42%, Denmark 39%, Sweden 37%, Poland 36% and France and Germany 30%. It was a major application area in all the other countreis except for Singapore, where welding accounted for less than 2% of the supply.

Assembly was the largest application area in Singapore, Japan and Finland, accounting for 84%, 47% and 26%, respectively, of the total new robot installations. In view of the size of the electronics industry in the two first mentioned countries, the high shares of assembly robots are not surprising. The share for Finland, on the other hand, is more surprising as it differs so significantly from the shares in other European countries.

9. The supply of robots in 1995 by major industrial branches

The United Nations documents says that for every 10,000 people employed in the motor vehicle industry there were over 800 robots in Japan, about 400 in Italy, 300 in the United States, 250 in Sweden, 230 in Germany and just under 200 in France and the United Kingdom.

The transport equipment industry, in particular the motor vehicle industry, is often regarded as the "vehicle" for robot diffusion. This is certainly so in Spain, Germany, the United Kingdom, France, Taiwan province of China and Australia. In those countries the transport equipment industry accounted for more than 40% of the 1995 supply. In Italy, Poland and Sweden the same industry received about 35% of the 1995 supply. Taking into account the fact that many subcontractors to the motor vehicle industry are classified in other branches, notably in the metal products industry, machine industry and electrical industry, the real importance of the motor vehicle industry is even higher.

The only major motor vehicle producing country with a share under 30% was Japan. In 1995, the transport equipment

Table I. Yearly supply of robots 1990–95 and forecasts for 1996–1999.†

							FORECAST			
Country	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Japan	60,118	56,775	38,874	33,502	29,756	38,553	46,500	56,500	67,000	77,100
United States	4,327	4,466	4,581	6,048	7,634	10,198	11,700	12,900	14,200	15,600
Germany	5,845	5,900	5,250	4,325	5,125	7,335	7,700	8,200	9,000	9,900
Italy	2,500	2,036	2,478	2,471	2.408	3,120	3,200	3,500	3,900	4,300
France	1,488	1,257	1,013	974	1,197	1,384	1,500	1,700	1,900	2,100
United Kingdom	510	747	624	591	1,086	792	1,000	900	1,200	1,600
Big six	**74,788**	**71,181**	**50,800**	**47,911**	**47,206**	**59,382**	**71,600**	**83,700**	**97,200**	**110,600**
Austria	299	290	248	214	276	280				
Benelux a/	375	260	587	438	600	700				
Denmark	79	63	32	35	65	64				
Finland	152	131	96	109	131	212				
Norway	34	28	21	28	32	41				
Spain	446	536	780	461	542	830				
Sweden	328	308	451	252	648	461				
Switzerland	425	175	350	450	500	500				
West-Europe-8	**2,138**	**1,791**	**2,565**	**1,987**	**2,794**	**3,088**	**3,700**	**4,300**	**4,700**	**5,200**
Czechoslovakia	153	51	0	0	0	0				
Hungary	61	30	8	10	8	15				
Poland	26	98	16	21	12	14				
Slovakia			50	63	26	25				
Czech Rep. a/			100	100	100	100				
Slovenia			118	15	27	20				
East-Europe-6	**240**	**179**	**292**	**209**	**173**	**174**	**200**	**300**	**400**	**500**
Australia	153	154	118	145	158	214				
Rep. of Korea	1,000	1,080	2,000	3,100	4,575	6,336				
Singapore b/	186	281	318	1,751	4,010	4,010				
Taiwan P. of C.	328	397	529	509	589	630				
Asia-4	**1,647**	**1,912**	**2,965**	**5,505**	**9,310**	**11,190**	**14,000**	**17,500**	**21,900**	**26,300**
Former USSR a/	1,885	796	0	0	0	1,000	1,000	1,000	1,000	1,000
Other countries a/	270	400	400	650	550	700	900	1,200	1,600	2,100
Grand total	**80,948**	**76,258**	**57,022**	**56,262**	**60,033**	**75,534**	**91,400**	**108,000**	**126,800**	**145,700**

Sources: ECE, IFR and national robot associations.
a/ Estimated by the ECE and IFR secretariats, for some or for all of the years.
† Note: Permission to publish this table is given by the United Nations Information Service UN/ECE, Information office, CH 1211 Geneve 10. Tel: +41-22-9172893. Further Information including graphs of the number of robots per 10,000 persons in industry and also other data of the yearly supply of robots in the period 1990–1995 and forecasts 1996–1999 for Japan, USA. W. Europe, Asia-4, all other countries and for the world as a whole, are available form this UN Office.

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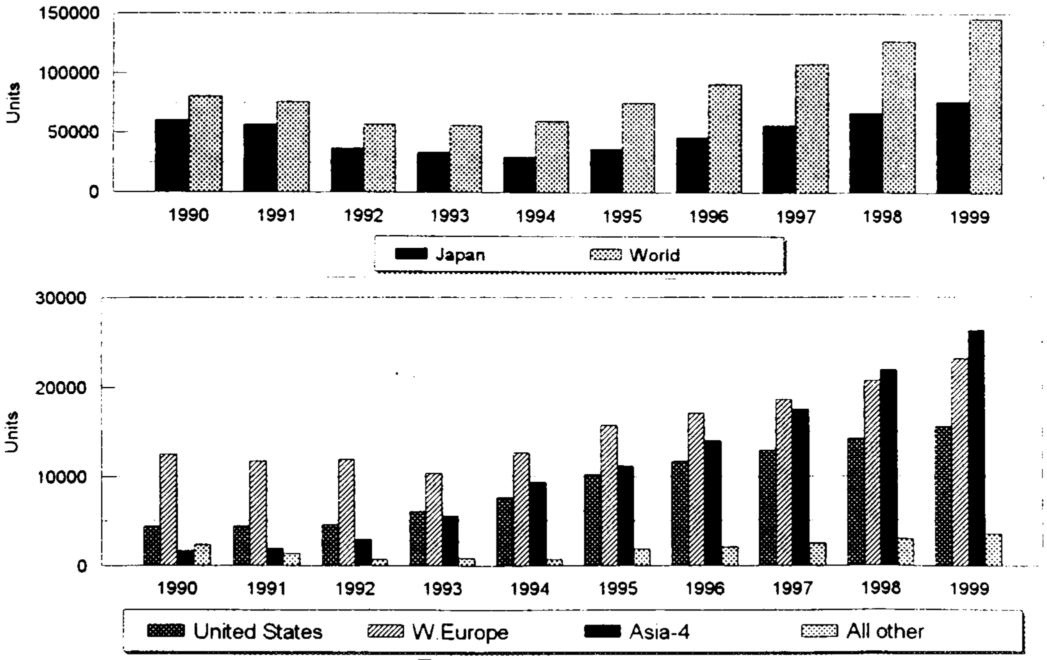

Fig. 1. Yearly supply of robots in 1990–1996 and forecasts for 1996–1999.

industry accounted for 23% of the net increase in the total robot stock.

The electrical machinery industry had a surprisingly low share of total robot stock except in Austria, Finland, Japan, Poland and Taiwan province of China. In all these countries this industry accounted for more than 20% of the 1995 supply. As concerns Japan, which is a world leader both in automotive and consumer electronics production, it seems as if the electrical industry is now the "vehicle" for diffusion, a role which the motor vehicle industry played in the 1970s and early 1980s. The motor vehicle industry is still, however, the second largest user branch.

The potential for expansion of robotics is enormous. If other industrialized countries were to approach the robot densities of Japan and if industry in general were to reach only half the robot density of the motor vehicle sector, the robot stock would increase manyfold, and this is not counting the potential for robots in the service industries.

10. Forecasts for 1996–1999

Continued booming markets in the United States and western Europe, which started already in 1993, and a recovered Japanese market will, according to ECE/IFR forecasts, result in impressive growth in the world market in 1996 of about 20% over the 1995 level. In 1997–1999 it is forecast to drop slowly to about 15% per year. In terms of units the world market is estimated to increase from about 75,000 units in 1995 to over 90,000 units in 1996 and to about 145,000 in 1999 (see Table I and Figure 1.)

In the period 1995–1999, the gross yearly supply in Japan is forecast to more than double, from 36,500 to 77,000 units. In this context it should be noted that a very large share of the new robots supplied will replace older robots taken out of operation. In 1995, for instance, the number of new robots installed amounted to 36,500 while the operational robot stock grew by only about 10,000 units, implying that more than two thirds of the Japanese supply were replacement investments. In the United States supply in the period 1995–1999 is projected to increase from 10,200 to 15,600 units, from 7,300 to 9,900 units in Germany, from 3,100 to 4,300 units in Italy, from 1,400 to 2,100 units in France and from 800 to 1,600 units in the United Kingdom. As concerns the United States, the 1996 half year result supports the optimist growth perspectives for that country.

The combined supply of Australia, Republic of Korea, Singapore and Taiwan province of China is forecast to grow from 11,200 units in 1995, of which, however, a larger share is simple robots than in Europe and North America, to 26,300 in 1999. As was previously shown, the Republic of Korea is now the world's fourth largest robot market both in terms of units and values.

In the eight smaller western European countries the market is forecast to increase from 3,100 units in 1995 to 5,200 units in 1999.

In terms of units, it is estimated that the world stock of operational industrial robots will increase from just under 650,000 units at the end of 1995 to just over one million units at the end of 1999, of which about half in Japan, just under 100,000 in the United States, 76,000 in Germany, 33,000 in Italy, 17,000 in France and 11,000 in the United Kingdom. As, in the same time, the number of personnel in industry in the best case will be stable or only grow modestly, the density of robots measured as the number of robots per 1,000 workers will continue to surge.

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