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Reports and Surveys

ADVANCES IN ROBOTIC TECHNIQUES

1. Robotics in Medicine

There have been a number of reports in this section of the progress being made in applying robotic techniques to medical processes. High on the list of achievements in this area have been the attempts to help in surgical operations. Already reports here have dealt with improved aids for surgeons with increased facilities for viewing and of producing images of the patient's progress. Indeed, operations assisted by links with remote centres of expertise and with internet information databanks are no longer unusual. All of these facilities and devices have been, in the main, aids to the operating medical staff but automated surgery still remains a remote goal, although there are many experimental systems in existence. From the Pennsylvania Hershey Medical Centre, USA, however, comes a report of a truly robotic heart surgeon called *Zeus*. On this occasion it appears that *Zeus* is not some robotics researchers speculative design for an automated medical robot but a working system that is starting its medical trials in a real-life hospital.

Heart surgery has always been a difficult process and includes many challenging surgical procedures which have had to be carried out by human hands which are not always able to perform accurately on all occasions. *Zeus*, therefore will be welcomed and if its clinical trials are successful, it will not only make a much needed contribution to cardiac surgery but also to the endeavours by medical researchers to getting official approval and, indeed, encouragement to use and develop robotic devices in medical applications.

Clinical trials for *Zeus*. It is reported that the clinical trials of *Zeus* are proceeding and are considered to be most encouraging. The head of cardiac surgery at the Hershey Medical Centre, Dr Ralph Damiano has carried out the suturing in a four-hour heart bypass on a 70 year-old woman. A report from the hospital says that the patient was well and a recovery was expected. The same procedures are to be carried out by Dr Damiano on some ten more occasions as part of the trial programme. So far, however, the robotic surgeons have not been allowed to perform alone but they are used by the human surgeon to perform 'tricky procedures' on their behalf. All the advantages of a robot device can be appreciated in such situations where the robot can keep a steady 'hand' holding instruments steadier for longer and make consistently more precise movements than even the most competent human.

It is reported that one of the robots most important assets is that it can work through very small incisions in the patient's chest and consequently reduces the trauma suffered by many heart patients. We are told that often in such operations the patient's chest cavity has to be split and opened to give the human surgeon access to the damaged organ. It is hoped that systems such as *Zeus* will be developed in the future so that this need to open the chest of the patient will not be necessary and operations will be carried out through these very small incisions that are currently in use in 'keyhole' surgery. At present patients operated on using *Zeus* are carefully monitored by the human surgeons and the process of the operation watched on a monitor fed pictures by the robot arm that holds the surgical instruments. The monitor's camera is moved by voice commands but handles controlled directly by the surgeon are used to manipulate the instruments and perform the procedure.

Such robotic devices will, of course, be slowly introduced into not only heart operations but all such medical procedures where the robot's characteristics are deemed to be required. Human participation and monitoring will still be regarded as essential even when the most sophisticated of robotic devices are in use. Both patients and surgeons will undoubtedly continue to demand this.

2. Artificial brain for robots?

Research announcements often include the word revolutionary and perhaps we can be forgiven for being sceptical about its meaning. The media are usually guilty of adding it to researchers' claims to attract attention and to 'sell' the copy. This announcement, however, comes from the University of Sussex, United Kingdom, and has been published in its original form as:

> "Dr Phil Husbands and Professor Michael O'Shea of Sussex University announced that they have transformed the network of artificial brain cells in a robot by using a toxic gas found in human brains. The result is a new artificial brain called a 'gasnet'".

The additional information gives describes the gas, which is nitric oxide, as integral to the workings of the brain, where it enables nerve cells, the neurons, to communicate with each other. The researchers say that the discovery that nitric oxide carried messages was:

> ". . . a completely new way of thinking about how the brain works. It could boost the attempts to replicate the human brain in robots. The development

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'transforms robots' from being pretty slow and stupid to being faster, more adaptable and clever."

Professor O'Shea and Dr Husbands are co-directors of the University of Sussex Centre for Neuroscience and Robotics and details of their researches have been published in this section on many occasions. We now look forward to receiving more information about their new endeavours.

3. Robotics for the people

The Japanese electronics giant Matsushita is developing hi-tech robot cats which have been designed to communicate with their owners and combat loneliness. This is an unusual project involving an application where high level research into technology has been applied to the problems of society. The result of this project will be, it is claimed, that thousands of elderly Japanese who live alone, will have a cuddly, 'talking cat' in their homes. This is but one example of the use of the developed robocat at the start of a government scheme to use robots to ease the problem of an ageing population.

This is a three-year project which has been sponsored by the Health and Welfare Ministry. The result has been the birth of *Tama* the prototype of the new world of robocats. *Tama* is said to be some 9.5 inches high and has a furry coat that conceals some very sophisticated electronics. These include sensors and circuitry that will allow her to distinguish between people's voices and to respond to simple questions and greeting with verbal answers. A memory unit allows some 50 different replies to be formulated, all given in a 'perky, female voice'. The developers say that when scolded the cat answers:

> ". . . with a goodhumoured query: 'Why don't you play with me?' When stroked, *Tama* wiggles and shifts her paws."

Researchers involved with the project say that they have investigated the work of animal therapists; and have been encouraged by the claims that such therapy can delay dementia. *Tama*, it is believed will have uses other than relieving senile dementia since cats have recently been the subject of experiments involving humans. These have investigated the affects on humans of stroking or cuddling animals as a means of reducing stress. Other conditions have been shown to have been improved by the presence of an animal in a household. Loneliness among people of all ages can be countered, for example.

Matsushita are continuing with the project and the robocats should be appearing mid-1999. Obviously the results of this project and other experimentation and application will be awaited but the potential is good and robo-animals may yet take over from the 'real thing'. This is an example of a project that if successful can contribute, using robotics techniques, to a serious problem that exists in society.

AUTOMOTION AND ROBOTICS WORLDWIDE

1. Australia

What is a robot? Definitions have abounded over the years and some uncertainty has always tinged the statistics presented to inform us of the current robot population and future trends. It is as if the World's politicians have got hold of the figures and put an appropriate gloss on them. It does, of course, suit countries to have one definition but not others. There is concern expressed in the Newsletter of the Australian Robotics and Automation Association (No. 57, p. 6, 1998) about the International Federation of Robotics (IFR) and the United Nations definition of a robot given in the UN/ECE current report on robot statistics*. This year, however, the report has a new title which reflects the IFR's decision to provide statistics of service robots as well as manipulating industrial robots.

The IFR's preliminary definition of a service robot, however, may not please all its supporters. It states that a service robot is:

> "a robot which operates semi- or fully autonomously to perform services useful to the wellbeing of humans and equipment, excluding manufacturing operations."

It has already been questioned by some bodies as lacking in precision. It has been suggested, for example, that some robots used in non-manufacturing industries can be counted as both service robots and as manipulating industrial robots.

Using this definition the report estimates that the total stock of operational manipulating industrial robots reached 711,500 in 1997 (stock at beginning of 1998), a growth of 6% from 1996. Some 84,900 robots were considered to have been installed in 1997. Some robot associations consider the statistics to be only approximate and perhaps correct to within several thousands in the case of the world stock of service robots.

2. Italy

The Italian Machine Tool, Robots and Automation Manufacturers' Association UCIMU–Sistemi per produrre** have reported that 1999 will be another good year for the machine tool, robot and automation sector. An increase is forecast in production (+6.4% at current prices) and in employment (+2.7%). The Association says that this year will be another year of growth and consolidation of the excellent results obtained in 1998. This is the view expressed in Milan and reported to the world's press at the traditional end-of-year meeting of President and the General Manager of UCIMU-SISTEMI PER PRODURRE, Flavio Radice and Alfredo Mariotti.

According to the estimates of the Association's Study Centre, production levels in the coming year should reach a value of ITL 7,446 billion, i.e. at current prices a 6.4% increase on 1998. This will be made up of ITL 4,265 billion

* World Robotics 1998. A summary is given later in this "Reports and Surveys".

** For further information about the Association contact: UCIMU–SISTEMI PER PRODURRE, Associazione Costruttori Italiani Macchine Utensili, Robot e Automazione, Italian Machine Tools, Robots and Automation Manufacturer's Association, viale Fulvio Testi 128, 20092 Cinisello Balsamo MI (Milan, Italy). Tel: +39 0226255.1. Telefax: +39 0226255.214/.349. http://www.ucimu.it. e-mail: ucimu@ucimu.it.

for exports (+6%) and ITL 3,181 billion for the domestic market (+7.1%).

A marked increase in employment levels is also expected in the 1999 (+2.7%), which should reach about 34,500. Thus it is estimated to improve on the good results obtained in 1998, when there was an increment of 3.5%. There is also an improvement in the trade balance (+7%), which is around ITL 1,879 billion, and in consumption (ITL 5,567 billion, +6.3%).

On the whole, therefore, it is expected to better the positive results obtained this year. The near final estimates for 1998 indicate that there was a growth in production of around 9.3% (at current prices) as compared with 1997, approaching ITL 6,995 billion.

This is a considerable expansion, following the consolidation in the two-year period 1996–97. This result is certainly partially due to the increased volumes of orders for machine tools, which in the first nine months of the year rose by 16.6% at constant prices (+43% from January to March).

In particular, in 1998, there has been an increase of 8% in the exports of machine tools, robots and automation for industry for an equivalent of ITL 4,025 billion. As regards the most important machine tools, the exports in the first eight months of the year were to Germany, France and above all Spain, but also to markets in central and eastern Europe, north America, China, Taiwan and Latin America.

An increase of 11.2% in deliveries to the domestic market can be estimated in 1998, for a value of ITL 2,970 billion.

Thus in a favourable context, UCIMU–SISTEMI PER PRODURRE has emphasised the need to create the foundations for consolidating industrial growth and the competitiveness achieved on domestic and international markets. The Association has therefore stressed the importance of a measure which would make it possible for small and medium-sized companies investing in production equipment to amortise as they choose the cost of this equipment in the first three years. The Associations' president declared that the proposed law, presented in Parliament last November 9th, (1998) entitled 'Regulations for reinforcing the Italian industrial system' is supported by the Association, as is the draft law 'Measures in favour of a deregulation of the amortisement constraints for innovative production equipment' presented to the Senate in December 1997.

Mr Radice also said that the implementation of the UCIMU–SISTEMI PER PRODURRE proposal could represent an important opportunity for growth, not just in this sector but also for the Italian industrial system as a whole. Incentives for modernising the stock of machines and therefore technological renewal could in fact contribute to reinforcing Italian businesses to meet the new challenges of the market.

3. United States

BEAM robots are usually small bug-like, solar powered devices created from scavenged parts and from springs and wires, bits of old electronics from cassette players, discarded pagers or any other equipment of a past era. These robots invariably have no sophisticated computers, microprocessors and certainly do not rely on complex software. They are more often than not small, simple, cheap to make, and tough in construction.

These are the robots of the enthusiastic amateur, the hobbyists, the keen student, but also it seems they are used by the engineer and scientist. The range of users is only matched by the wide range of robots they have constructed and use.

BEAM stands for Biology, Electronics, Aesthetics and Mechanics, and we are told, was founded by one, Mark W. Tilden, who is an engineer and physicist at the Los Alamos National Laboratory in New Mexico, USA. This is said to be one of the more vigorous subcultures for robot developers. Dr Tilden was asked his views on robots and the future trends. On personal robots he believes that:

> "There are three reasons we do not have them: Autonomy; Complexity and Terminatorphobia. Autonomy in that we cannot, try as we may, commercialise a working machine with the independent-power life span of a housefly. On complexity, if 60% of all VCRs are flashing 12.00, who is going to take the time to program a robopuppy that is too fragile to play with? As to the Terminator-phobia, or more exactly, the cultural leftovers of the Industrial Revolution, not a day goes by without the 'robots will take over' message blared from many media sources. The fact is that without humans, all machines stop."

We may or may not agree with all of these sentiments but it does echo the opinions of many robotics researchers who take a robust view of where we are in the so-called 'robot revolution'.

Dr Tilden also has indicated that he does not follow the line of many robotics developers who see robots playing an active part in the home. He believes that robots should be designed and placed in the outside world, rather than in the home. There he says, they can perform unsupervised tasks for years without human supervision. He gives examples of such tasks as rain forest planting, Chernobyl-cleaning, landmine-stomping, moon-prepping machines. These he describes as 'wild robots' and he believes that they must first prove themselves by being seen to work before there is an interest in domesticating them. He outlines a scenario in the home where:

> ". . . a collection of slow automatic devices for house and garden that will passively, reliably, do the job of removing small inconveniences from your life."

More information BEAM Robotics from: sst.lani.gov/robot.

FLYING ROBOTS

Recent reports from the United Kingdom describe how scientists are developing robots that can fly like insects. The technology that is being developed is, it is claimed, capable of revolutionising our understanding of the nature of flight.

In particular, the Cambridge University scientist Charles Ellington who is known for his research in the aerodynamics of insects, has developed a robot microaircraft which he expects to produce under a new £1.6 m research contract. The robot aircraft will have a 3ins–4ins wing-span and will

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be designed to fly surveillance missions inside buildings. At present it is reported that he is also working on a 3ft. wingspan model that is based on a hawk moth. The craft is called an entomopter and it will use a chemical engine to flap its wings like a moth that crawls about and also to be able to flit from in-trays and out-trays taking photographs and recording conversations for transmission to satellites.

The British researchers tell us that there is a real need for such a robot project. This is confirmed by the report that a joint venture with US research group has been agreed.

It has been suggested that this new understanding of insect flight will make flapped wing flight by aircraft a possibility for the first time. Interest in the UK has not been strong and it is in the US that researchers sees this work as offering great opportunities for development. We have been reminded that nothing in creation has been developed with a fixed wing and a power thrust, but just with flapping wings.

An advisor to the Smithsonian Air and Space Museum, Washington, US, stated that:

> "Technically, this is a very exciting development. Micro air vehicles with flapping wings use different aerodynamics from birds, and I think we will continue to use fixed-wings for manned flight, but this will fill one significant corner of the flight spectrum."

Currently it is reported that Charles Ellington and the nine-strong team from his laboratory at Cambridge University Department of Zoology will join scientists at the Georgia Tech Research Institute, Atlanta, US to develop a working entomopter. This is a three-year Darpa contract to build a controllable stable, flapping machine.

The new machine is likely to be powered by a reciprocating chemical muscle being developed at the Georgia Tech. Batteries are going to be too heavy and ordinary combustion engines too big for the new entomopter. The reciprocating chemical muscle has been designed by Robert Michelson of Georgia Tech and it is described as a catalyst that breaks apart a chemical to release heat and a gas that drives the wings rapidly and releases up to one watt of electricity. Additional micro-electronics, controls and sensor systems will be added.

The design of the entomopter would allow it to fly as a remote controlled aircraft quietly around or in a building, for example, using its ultra sonic detectors to avoid obstacles and chemical detectors to locate humans. The interest therefore of the US Department of Defence is understandable. Even so, although there may be a need for a larger version of this spy robot using the insect technology science is also giving an opportunity learn more about aerodynamics of insects as well as the building of new chemical power devices.

INNOVATIVE PROJECTS

1. Small screen access to the Web

Researchers at the Middlesex University's School of Computing Science (UK) are developing new design principles and tools to facilitate interactions with Web sites from devices with small screens. This is a project that is being carried out in collaboration with Reuters, the global information and news groups.

The participants of the project maintain that:

> "Users of handheld devices with small screens are increasingly seeking access to Web sites designed for conventional 'large' desktop screens. Yet little systematic research evidence is available on the usability of Web interaction through smaller displays."

The first phase of the project in the new endeavour at the University's Interactive Design Centre (IDC) and at Reuters has focused on obtaining empirical information on interactive task performance with smaller screens. In this initial study it was found that the users of small screens were currently 50% less effective in retrieving information from the Web than users of devices with large screens. The project's leading investigator, Dr Matt Jones explained that:

> "Findings like this are helping us to identify design guidelines for small screens. For example, small screen users seem to prefer interfaces with search elements and focused navigation paths that get directly to the information required, such as the financial performance of a particular company."

The resulting design guidelines will be embedded in a tool for extracting information from Web sites to adapt them automatically for small screens. It is reported that a pilot tool for this work will be available this year.

The IDC researchers have the advantage of access to Reuters commercial Web services such as *Off-Trading Floor* products incorporating financial data. Reuter's research manager Richard Willis regards the use of handheld Internet-enabled devices, we are told, as the latest step in the company's history of pioneering novel ways of delivering information content to customers. He asserts that:

> "With a global reach of over 100 million subscribers for digital mobile communications, our ability to provide effective Web interaction through small screens opens vital market opportunities.'
>
> The work with Middlesex has already given us vital feedback on usability and navigability for this demanding new delivery medium. We also expect to gain insights into the design and delivery of future systems. And our general discussions with the researchers have been extremely rewarding in promoting the cross fertilisation of knowledge."

This project builds on other IDC initiatives such as:
(a) distributed Web Authoring – tool development (Professor Harold Thimbleby)
(b) hypertext navigation (Dr Yin Leng)

2. Virtual Companies

Developments in Europe have highlighted the importance of teleworking. A new framework in which to discuss this new way of working and to debate the significant impact of telework on work practices is now in evidence. It has also

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introduced a new concept in management practice called *Companies in Cyber Space*. Much of this development is the result of the successful *European Telework Week* which was held at the end of 1998.

There is, however, no completely satisfactory definition of teleworking. Does it, for example, mean that someone works from a place other than his or her normal place of work? Or does the concept merely mean working at home without travelling to some central work centre? Unfortunately, no acceptable definition can be given but even so, Europe has attempted to assess the numbers involved.

The best estimates, available for Europe only, indicate that some 4 million Europeans are currently involved in some form of telework activity. This is estimated to be about 2.5% of the workforce.

Erberhard Köhler, who is a co-ordinator for information technology research in the *European foundation of the Community (EEC)* views the development of teleworking as part of the evolution toward greater flexibility in many aspects of work. He maintains that:

> "These developments reflect the move away from the standard assumption that work must be performed in a central workplace where people come to work and then go home again. The emphasis is growing on greater spatial flexibility, in working time and in work contracts."

Virtual Companies are now possible using modern technology.

Köhler is currently researching a new form of work organization – the virtual company – an electronic networking company where a number of people with specialist skills come together, usually via the internet, to do a specific task for which these skills are needed. The multi-media industry is a typical example. In the virtual company scenario, a sound engineer teams up electronically on the internet, with computer, graphic and text specialists to compete for a large contract. If successful, they carry out the job, operating as a virtual company for a limited period.

Operating as a virtual company, Köhler together with a team of experts have produced a guide for virtual companies in CD-ROM format in German and English. It includes background information on: how decentralized working has developed; the opportunities and the pitfalls of the virtual company; and the route companies and individuals can take towards electronic decentralization. The CD-ROM has links to the web site of the University of Berne, which carries case studies of operating virtual companies.

The CD-ROM features a questionnaire which assists companies evaluate their own position vis-a-vis decentralisation. It also makes suggestions as to steps which need to be taken to move a company closer to virtualization. The CD-ROM* has already been presented in the UK at the Henley Management College last year.

* The *European Guide for Virtual Companies – A framework for action* – CD ROM costs ECU 20. On request 100 copies are available free. In return the Foundation is anxious to have feedback from users which can be submitted via an electronic evaluation form incorporated on the CD-ROM. *Contact: camilla-.gallidabino@eurofound.ie.*

NANOSCALE DEVICES

The 'IT-Update' from the UK's Engineering and Physical Sciences Research Council (EPSRC) *Impact (No. 21, 1998)*, gives details of an innovative method of making ultra-high resolution nanoscale devices using Silicon-Germanium (SiGe). The method has been discovered by researchers working on an EPSRC project on advanced silicon structures. The project involved the UK's Universities of Cambridge, Liverpool, Warwick and Imperial College.

The project report states that "the new device fabrication route takes advantage of damage caused during the electron beam irradiation process that etches patterned circuits into a layer of 'photo-resist' material on a semiconductor base." It was discovered unexpectedly as part of the project's investigation into the ultimate limits of nanofabrication, which seeks to create circuits at extremely small scales. Conventional high-resolution electron beam lithography has usually involved a polymer-based resist like PMMA which hardens when exposed to the beam. One of the aims of the project was to study how silicon dioxide on a SiGe base could be used to provide higher resolution circuits than is possible with PMMA.

The EPSRC's project's principal investigator, Dr Mark Welland, a researcher at the Department of Engineering at Cambridge University, UK maintains that:

> "We successfully developed a masking layer of low-temperature plasma oxidised silicon on a SiGe heterostructure. However, we found it was impractical to apply to the fabrication of useful devices."

He added that the degree of damage caused to the SiGe by the high dose levels required for irradiating the silicon dioxide was the main barrier to crating practical devices. It was realised later that the team could exploit the damage effect to eliminate some process steps when patterning nanoscale structures within SiGe. The project also demonstrated how this direct damage technique could be used effectively to pattern nanoscale structures with conventional resists.

The report maintains that:

> "it quantified the ultimate resolution limits of PMMA to a new precision through the most comprehensive study of its kind to date. No clear evidence was found on how to improve the ultimate resolution, but much valuable data was gathered on potential approaches, like ultrasonic agitation."

The project showed how it could benefit from close collaboration at Cambridge between the Engineering Department and Professor Mike Pepper and Dr Douglas Paul at the Cavendish Laboratory.*

Important contributions were also made by Warwick University's Physics Department, which has pioneered work on SiGe, and the Engineering Department at Liverpool University, a world leading centre on plasma oxidisation growth. Imperial College assisted by providing additional supplies of SiGe material.

* *Readers may wish to know the Web link for the Nanoscale Science Group at Cambridge UK is: www2.eng.cam.ac.uk/~nano-www/.*

The three year project ended recently. Dr Wellend led its latter stages, after its original manager, Professor Alec Broers, became Vice-Chancellor of Cambridge University. The results of the project are being built on at Cambridge in the Esprit SIQUIC and NANOWIRES projects and EPSRC-funded research into applying irradiation damage technology to manufacture superconducting devices and to fabricate SiGe-based quantum devices.

PERSONAL ROBOTS

1. Role of personal robots

A report in the *New York Times* (Circuits, August 1998) reminded us of the predicted role of personal robots. Heralded as 'the robots of everyday life', progress in producing viable machines has been somewhat slower than forecast in the 1970s. Specialised robots are, of course, already in widespread use in such areas as manufacturing, medicine, law enforcement, exploration and other commercial applications. But what, this report asks, has happened to personal robots?

It is significant to note that two decades ago the idea of personal computers appealed to only a handful of hobbyists. Yet today PCs are a multimillion-pound industry. Now, however, the recent reports of advances in computer science, artificial intelligence and engineering, together with a new consumer awareness, we are told, may soon create a powerful personal robotics industry.

At first this report suggests that personal robots would be concerned with one or more domestic tasks, such as mowing the lawn, vacuuming the floor, watering the plants, serving drinks, delivering mail, feeding the pets, watching the house while the owner is away on vacation and helping disabled people do simple chores.

One example given is of the researcher who envisages armies of cheap and simple microrobots that will scurry from under the sofa at night to devour dust and bugs, washing the floor, cleaning the windows, etc. . . . Dr Gregory Dudek of the Computer Science Department at McGill University, Montreal, Canada is quoted as believing that:

> "Today's robots are weird, kludgy things. But then 20 years go people bought computers that were also awkward to use. That's the sort of change we're looking for in the robot industry. I do not think it will happen in the next two years, but in the next 5 or 10 years, certainly."

2. New initiatives

A number of personal robot initiatives are underway, and many organisations such as the KISS Institute for Practical Robots at Reston, Virginia, US, which is an educational organisation, are looking at the implications. Indeed, even robot speciality shops have seen their business in the US tripled over the last two years. One company called Mondotronics, San Rafael, California (Website: www.robotstore.com) has sponsored a series of robot exhibitions and sells only robot construction kits.

At the same time it is considered that most interest in the US is now concentrating on consumer robots supplied in kit-form. *Lego* blocks form part of some of the most popular kits. The *Lego* manufacturers have for some time been working with researchers at the Massachusetts Institute of Technology (MIT) to create computer-controlled toys. One of the first results of this research is the '*Lego Mindstorms Robotics Invention System*' which is on sale in North America (see: www.leomindstorms.com). The kit we are told, takes relatively sophisticated robotics technology and puts it into the hands of children (and many older enthusiasts!) who will receive for $200 a combination of light and touch sensors and motors and more than 700 *Lego* pieces together with a small, infrared-controlled computer built as an oversized *Lego* block. The brain of the system is made up of a battery-powered computer called RCX unit, and software. Users with no programming experience can assemble prefabricated modules of software on a computer in much the same way as they would snap together a model with plastic blocks. The resulting programs are then beamed to the RCX computer block by an infrared signal and the smaller computer puts the inventions into action. An example of some of the suggested experiments is given in a detailed construction manual which gives a variety of plans including one called *Refrigerator Fred*, which is a robot that answers the cosmic question 'Does the little light in the refrigerator stay on when the door is closed'. Using light sensors that cause a pair of plastic sunglasses to either hide or reveal his eyes *Fred* provides the answer. A slight modification yields a robot that can warn you of the approach of anyone who wants to gain entry to your room.

The importance of these experiments suggested by the developers is that they can be as simple or as elaborate as the user desires. So wide-ranging is the invention system that additional modules are to be sold that will enable users to create wild animals, sports robots and a replica of the Mars rover.

It would appear therefore that new generations of young people will be equipped with an awareness of robotics and hopefully an enthusiasm for the new ideas encouraged by automation advances. Meanwhile researchers at the Georgia Institute of Technology are developing a small mobile robot called Pepe (short for Personal Pet) which its developers say may one day be perceived as more than a friend or companion than as a robot. This like many of these robotics endeavours has a serious side. Dr Ashwin Ram from the Intelligent Systems Group of the College of Computing at Georgia Tech said that:

> "If you are going to put one of these robots in someone's house, you want it to interact naturally, with speech and gestures, the same sort of way you would interact with real pets."

To produce such a robot with intelligence and personality is no mean challenge. Dr Ram says that:

> "Our goal is to enable the robot to pick up the user's speech and gestures but also to understand the user's intentions, emotional state, needs and goals. It should, for example, figure out when you are tired, happy or playful, or when you do not want to be bothered."

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Another unusual robot described in this US report was on display at a recent National Conference on Artificial Intelligence held in Madison, Wisconsin. This prototype was a two foot aluminium robotic plant, attached to a PC, that slowly blooms, droops and makes alien noises depending on a text analysis of the owner's incoming e-mail messages. Called Plant No. 1, the 'Kind With Leaves and Roots' was developed at Carnegie Mellon University. The developers say that they envisage a class of 'intimate technology' robots that are more attuned to environments than to specific tasks. The aim being to produce a totally non utilitarian class of robots.

3. *Robot servants*

More useful perhaps is a robot servant. At the Madison artificial intelligence conference mobile robots roamed around the cocktail bar. By using combinations of sonar, computer vision, speech synthesis and other sensing technologies they were able to serve snacks to the human participants. A similar task is performed by robots at a London restaurant where they make food or wander around serving drinks whilst growling at customers to make way. This, of course, was a real world use of robots.

Dr Miikkulainen of the Computer Science Department of the University of Texas at Austin, an expert on neural networks and cognition, asked about robots performing these tasks, said that:

> "Robots used to be used for extremely close alignments on the factory floor, where everything is controlled. The trend now is to make them more open-ended and adaptive."

At the Robotics Institute at Carnegie Mellon, US. Dr Hans Moravec is reported to have written a business prospectus that outlines the development of 'autonomous free-ranging utility robots for the mass market by 2005'. Autonomous robots, he is quoted as saying, have the intelligence (functional) of insects. Today he says:

> ". . . the actual level of intelligence of computers is just starting to touch the lower vertebrate levels. As soon as 2010 we could have general all-purpose robots comparable in intelligence to lizards. Then there could be mouselike intelligence, with learning and adaptation, by 2020, and monkeylike intelligence by 2030.

It is only then, he believes, that we could be talking to a household robot and you would think that it is conscious. By 2040, he predicts that the four generation household robot could add a layer of reasoning and become human-like.

There are many World Wide Web links to consumer robots and the sites listed do, of course, provide links to other robotic sites on the Web and Usenet: For further information and interaction visit: Robotics Clubs: www.seattlerobotics.org; www.dprg.org; www.robotgroup.org; www.rdrop.com/users/marvin. Questions about robotics: www.frc.ri.cmu.edu/robotics-faq. Commercial sites: www.robotstore.com; www.legomindstorms.com.

WORLD ROBOTICS STATISTICS

1. *Summary of UN/ECE published statistics and forecasts*

Published by the United Nations Economic Commission for Europe (UN/ECE) in cooperation with the international Federation of Robotics (IFR), the *World Robotics 1998–Statistics, Market Analysis, Forecasts, Case Studies and Profitability of Robot Investment** contains a wealth of information. A few of its revealing conclusions are that there has been:

* The publication *Worlds Robotics 1998 – Statistics, Market Analysis, Forecasts, Case Studies and Profitability of Robot Investment* is available, quoting Sales No. GV.E.98.0.25, 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

Table I. Number of robots installed in 1997, estimated stock of robots in operation at end 1997 and forecast for year 2001

Country/region	Installations in the year			Stock at year end		
		Forecast	%		Forecast	%
	1997	2001	increase	1997	2001	increase
Japan	42,700	61,400	44	413,000	433,400	5
United States	12,500	16,900	35	77,100	114,800	49
Germany	9,000	12,000	33	66,800	95,700	43
Italy	3,700	4,700	27	28,400	39,100	38
France	1,700	2,400	41	15,600	19,000	22
United Kingdom	1,800	1,900	6	10,000	14,200	42
Big six above	71,400	99,300	39	610,900	716,200	17
Western Europe a/	3,800	5,600	47	27,200	40,900	50
Asia-4 b/	7,000	9,300	33	41,100	69,200	68
Other countries	2,700	5,600	107	32,300	46,800	45
Grand total	84,900	119,800	41	711,500	873,100	23

Sources: ECE, IFR and national robot associations.
a/ Austria, Benelux, the Nordic countries, Spain and Switzerland.
b/ Australia, Republic of Korea, Singapore and Taiwan, province of China.

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- A record investment in industrial robots in 1997
- A robust growth in industrial robot investment is forecast for North America and Europe until 2002 – for Japan and other Asian countries previous forecasts are revised downwards
- The number of robots per employee in industry continues to rise sharply
- In the next 10–15 years, dedicated service robots will be used extensively in a wide range of professional applications as well as in homes. A new substantial business area will be created

2. Record investment in industrial robots in 1997

The world robot statistics were published for 1997, with forecasts to the year 2000, in *Robotica* **Vol. 16**, part 4, pp. 374–379 and the corresponding Tables and Figures are included here for comparison purposes.

In 1997 a record number of 85,000 industrial robots were installed worldwide, surpassing for the first time the previous record of 1990 (see table 1 and figure 1). In the same period, Japan's share of new robot installations fell from 75% of the world total to 50%, marking a clear trend towards deceleration of the automation drive in that country. Although the 1997 robot investment in Japan was 43% higher than in the tough year of 1994, it was still only 70% of the record 1990 level.

For the United States and the major western Europe countries, on the other hand, robot investment was booming and in both 1996 and 197 all-time records were set. The 1997 robot investment in the United States, for instance, was almost three times as large as in 1990. In the United Kingdom it was 2.5 times larger and about 50% larger in Germany and Italy but only 16% larger in France.

One consequence of the slowdown in robot investments in Japan, compared to the booming 1980s and early 1990s, is that a large share of new robot installations is made up of replacement investment. While almost 43,000 new robots were installed in 1997, the stock of operational robots only

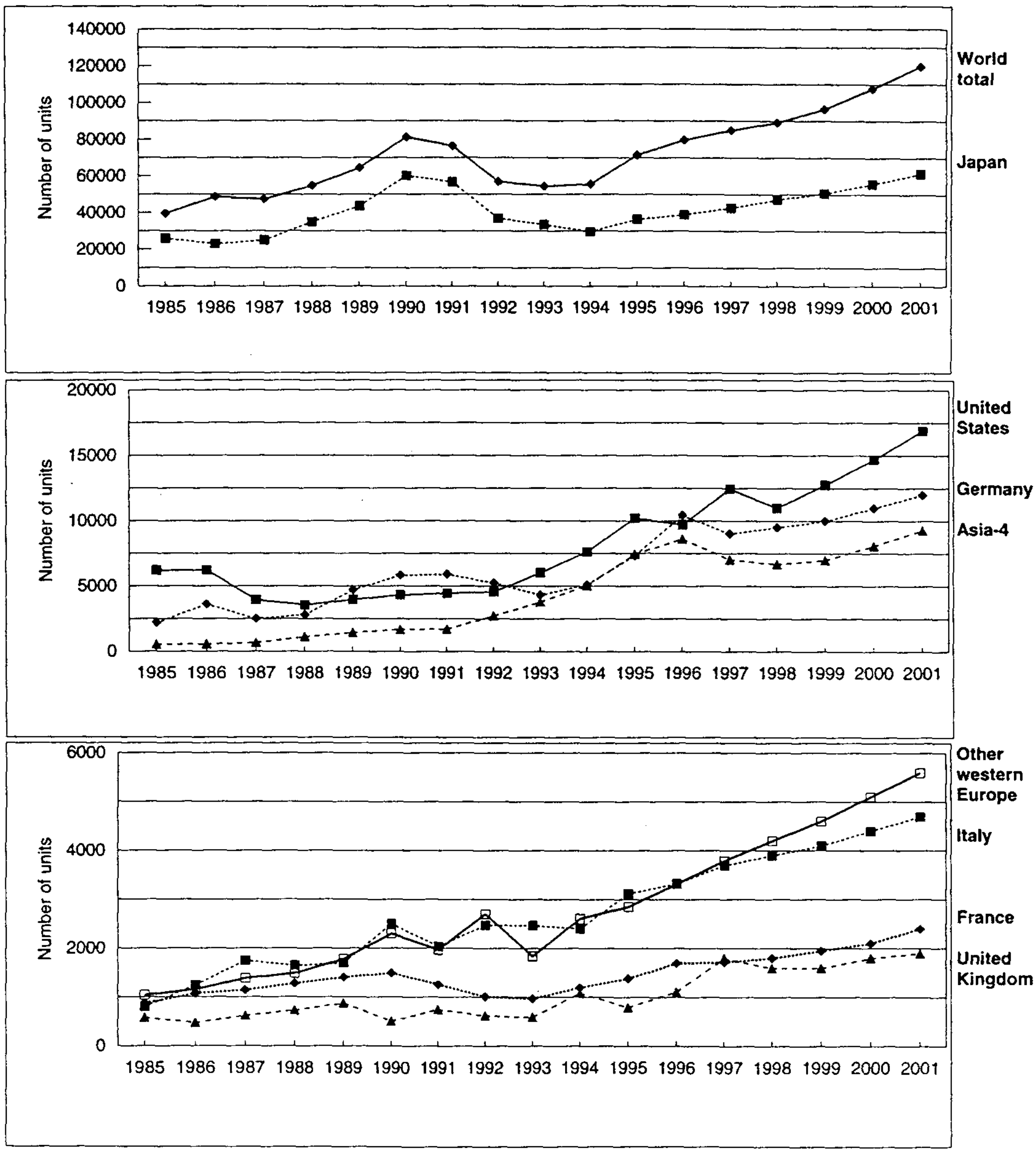

Fig. 1. Installations of industrial robots 1985–1997 and forecast to 2001 and inclusive

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increased by an estimated 13,000 units. In other words, more than two thirds of all the new robots replaced older robots.

In 1997, the market for industrial robots, in terms of units, increased by 6%. Total market value, however, fell by over 4% over 1996 to $4,8 billion. This drop in the world market, in dollar value, is mainly explained by the fact that the dollar appreciated against most other currencies. In this context it should be noted, however, that the value of robot shipments only accounts for 30% on average of the total system cost.

The market in the United States increased from $485 million in 1990 to almost $1,100 million in 1997. After the record year of 1996, it was expected that the market in Germany would fall back in 1997. The fall was, however, only 13%, in terms of DM, and the market amounted to about 1 billion DM. The market in the Republic of Korea, on the other hand, plummeted by almost 50% over 1996 to $143 million. While the United Kingdom market surged by 32% to £66 million, France recorded zero growth and a market of FF 585 million. The Italian market grew by 5% to 410 billion lire.

3. *Forecast to 2001 and inclusive – Europe and North America is catching up*

Worldwide investment in industrial robots is forecast to be about 40% higher in 2001 than in 1997. In the six major economies, almost the same growth is projected (see table 1). Taking into account the fact that a raising share of robot investment is directed towards replacement investment, in particular in Japan, the stock of robots in operation is forecast to increase from about 710,000 units in 1997 to about 870,000 units in 2001, an increase of 23%. This forecast is significantly lower than was forecast in previous years, which is exclusively the result of significant revisions downwards of the forecasts for Japan and other Asian countries.

While the stock of robots is projected to grow by only 5% in Japan between 1997 and 2001, it is projected to increase between 20% (France) and 50% (United States) in the other major economies (see Table I and Figure 1). Western Europe, excluding the four major economies, is also projected to have a robot stock in 2001 which will be 50% higher than in 1997. One can therefore conclude that although Japan continues to be the country with the highest penetration of industrial automation, the balance of automation is swinging back towards Europe and North America.

4. *The robot density continues to rise – more robots per employee*

When comparing the rate of diffusion of industrial robots in various countries, the robot stock, expressed in the total number of units, can sometimes be a misleading measure. In order to take into account the differences in the size of the manufacturing industry in various countries, it is preferable to use a measure of robot density. One such measure of robot density is the number of robots per 10,000 persons employed in the manufacturing industry.

Employment in the manufacturing industry fell in many countries in the period 1991–1993, owing to the recession. Although the economy recovered in 1994–1996, employment continued to fall in some countries while it stabilized in others. As at the same time robot stocks continued to increase, in particular as from 1995, there was a significant increase in the robot density in 1993–1996 in most countries. In 1997, the employment situation improved in many countries but as the increase in the robot stock outpaced the employment gains, the robot density continued to increase.

Japan has by far the highest density of robots. In 1997, it amounted to 277 units per 10,000 persons engaged in manufacturing industries. Germany has the second highest with 90 units, followed by Sweden and Italy with just over 60 (see Figure 2).* In the other countries in western Europe, Australia and the United States, the density ranged between about 20 and 40 units.

Figure 3 shows the 1996 robot densities (expressed as the number of robots per 100 people employed) in the motor vehicle industry. In this industry there were 9 robots for every 100 persons employed in Japan, 4 in Italy, between 3 and 4 in the United States, Germany and Sweden and about 2 in France and the United Kingdom. These figures would have been twice as large if the density had been measured as number of robots per 100 production workers.

As one robot generally performs the tasks of at least two persons it could be said that robots in the Japanese motor vehicle industry correspond to some 20% of the total labour force.

5. *Relative prices of robots continue to fall*

The unit value of robots for United States, Germany, Italy, France and United Kingdom peaked at just under $110,000 in 1991. Since 1990, there has been a continuous fall in the unit price of industrial robots. In terms of national currencies, the unit price fell by 21% in the United States between 1990 and 1997. In the same period, it fell by 25% in Germany, 19% in the United Kingdom and a record 41% in France. In Italy, on the other hand, it fell by only 5%.

The relative price of robots, i.e. the price of robots for a given set of performance indicators, in relation to labour costs has been falling rapidly. Since 1989, prices of robots relative to employee compensation in the business sector have fallen by between 30% and 50% in the United States, Germany and France, although there was a slight reversal of this trend in 1996 in the first two countries. It should be noted, however, that these calculations of relative prices do not take into account the improvements made in the quality and efficiency of robots, factors which would, if included, have made relative prices fall even more. Data on different types of robots being installed strongly indicate that for many countries there has been a gradual shift towards a higher share of more sophisticated robots. The calculations of relative prices above thus underestimate the true relative prices. With raising labour costs and falling price/performance ratio for robots, manual operations will successfully be replaced with robotic solutions.

* The Republic of Korea and Singapore would have had the second and third highest density but as these countries have a very high proportion of very simple robots they are for reason of comparability excluded from this ranking.

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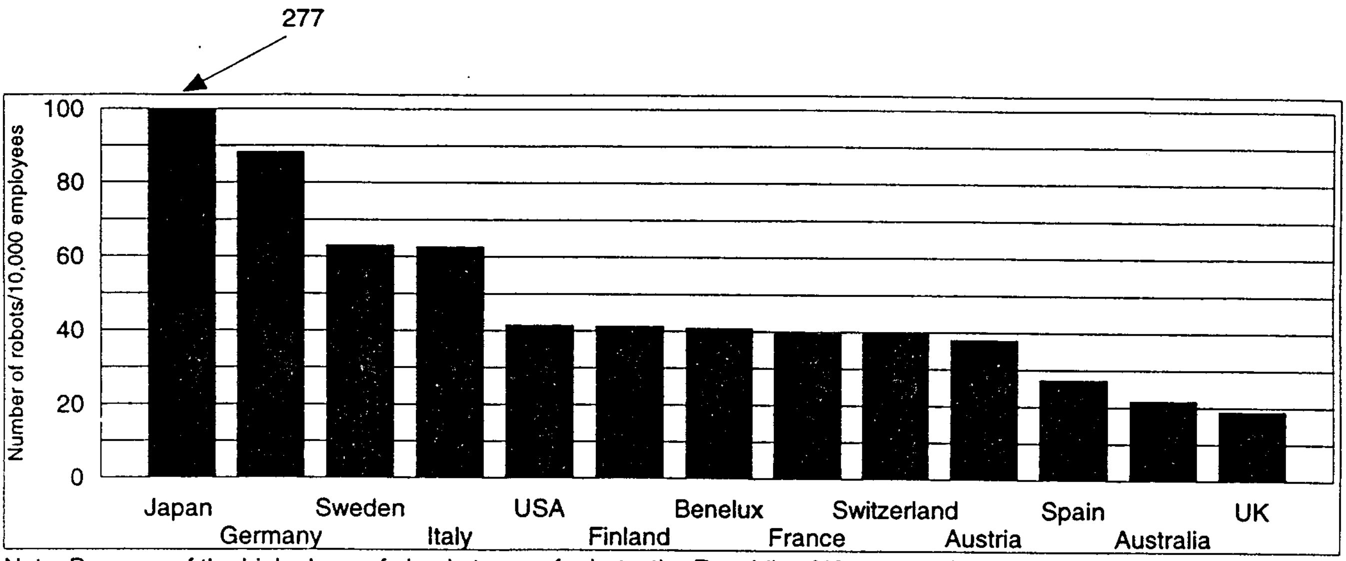

Note: Because of the high share of simple types of robots, the Republic of Korea and Singapore are, for reasons of comparability, not included in the graph. It should also be noted that the robot stock for Japan, Germany, Italy and Austria includes a higher share of simple robots than for the other countries listed.

Fig. 2. Number of industrial robots per 10,000 persons employed in the manufacturing industry, end 1997

Figure 4 compares the index of labour compensation in the business sector in the United States with the index of the average unit price of robots being installed, illustrating the widening gap between the two indices, the so-called "crocodile gap".

6. *Motives for investing in robots*

Readers of *Robotica* will also be intrigued at the report's views on what constitutes the motives for investing in robots. Apparently the reduction of labour costs is not the only objective.

The reduction of labour costs is, of course, a major motive for investing in industrial robots. With falling prices of robots relative to labour costs, robots are increasingly becoming a cost-effective alternative to labour. There are, however, several other motives for investing in industrial robots. The following ones can be mentioned:

- **Reduction in material costs.** In spray painting applications, e.g. of cars, there are examples where the targeted return on investment was almost exclusively achieved through a very significant reduction of paint consumption.
- **Higher quality.** Subcontractors to the automotive industry and the electronics industry, for instance, in order to stay in business, must be able to certify that they can deliver components with zero faults and within given limits of tolerance. In many cases the only way to achieve these objectives is through robots and automation.
- **Flexibility in the production volume.** Very often the targeted return on robot investments is based on the requirement that the robot operates in two shifts. If demand increases robot cells can easily be operated in three shifts without extra personnel. This also implies a higher degree of utilization in other pieces of equipment in the production system.

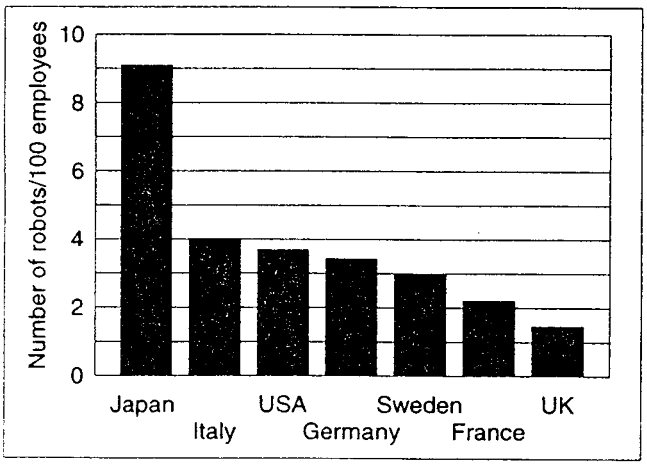

Fig. 3. Number of robots per 100 employees in the motor vehicle industry, end 1996

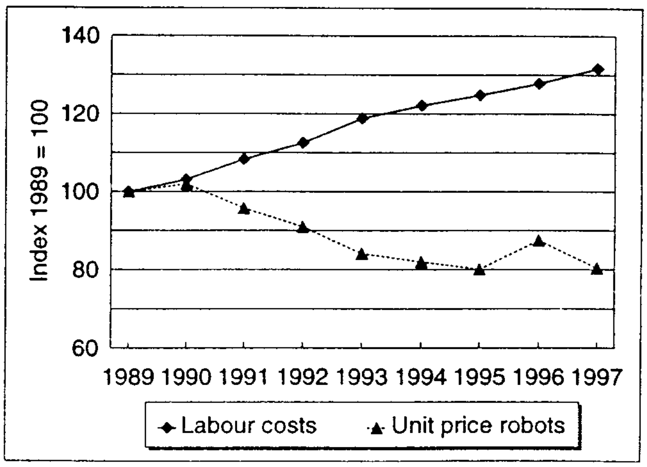

Fig. 4. Index of labour compensation in the business sector and of unit price of robots in the United States

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- **Improvement of the working environment.** Robots are often used in work processes involving heavy lifts, e.g. servicing machine tools with heavy work pieces, repetitive work, e.g. assembly or servicing machines with very short process cycles, handling of dangerous chemicals, human presence in an environment with heat and smoke (foundries, furnaces) or as mentioned above in secluded spray painting boxes. In all these work processes robots eliminate bad working conditions. As is illustrated in Case Study 4 of the present publication, the main reason for a small company in Sweden to invest in a robot cell was that it had difficulties in recruiting machine operators because of bad working conditions and a general shortage of labour in the region where it was located.

Some of these motives are illustrated in four case studies (from the United States, Germany and Sweden) which are included in the present publication. Generally, robot investment has a pay-off time of about two years.

7. Robotic Applications

The publication *World Robotics – 1998** also considers the impact and application of robots in a number of areas. These include sections on:

(a) The food and agricultural industries
(b) Major application areas for service robots

In the former it is reported that the robotization drive has not yet taken off as previously projected, and in the latter section it says that service robots is an area which is expected to take off in the next 10–15 years.

A more detailed look at these two important areas will be included in future issues of this section.

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* Readers may obtain more information about the publication: *World Robotics* 1998 from: Mr Jan Karlsson, Statistical Division, United Nations Economic Commission for Europe (UN/ECE), Palais des Nations, CH–1211 Geneva 10 (Switzerland). Phone: (+41 22) 917 32 85. Fax: (+41 22) 917 00 40. e-mail: jan.karlsson@unece.org. International Federation of Robotics (IFR), Box 5506, S–114 85 Stockholm (Sweden). Phone: (+ 46 8) 782 08 43. Fax: (+ 46 8) 660 33 78.