Robotica (2005) volume 23, pp. 131–138. © 2005 Cambridge University Press
doi:10.1017/S026357470400116X Printed in the United Kingdom

Reports and Surveys

AUTOMATION & ROBOTICS WORLDWIDE

1. Europe

1.1. Safety-critical systems. The importance of verifying safety-critical systems has been highlighted recently when the Embedded Systems Group (SEN2) and the Systems Validation Group (VASY) launched a collaboration agreement. Called SENVA, which represents *S*ystem *En*gineering and *Va*lidation, this joint research team will add strength to this important area of endeavour.

Both research teams have experience in the formal specification and computer validation of safety-critical systems. The teams also share a common methodology based on the theory of process algebras established by prominent scientists like Hoare and Milner. They develop robust software tools which are used in significant industrial case studies, in areas like railways, embedded systems and hardware communication platforms. In 2004 the SENVA team is to focus on the following themes:

- High-level specification languages
- tools for minimizing state space
- distributed algorithms for state space analysis
- compositional verification techniques

No one can doubt the importance of verification of safety-critical systems or indeed the research more generally carried out under the heading of Formal Methods. The fact that our systems are not proven but are in constant use in so many applications is still a cause of much concern. Robotics and automation is but one area that could benefit from progress in verifying systems that are assumed to work in all circumstances.

Information about this collaboration can be obtained from:
INRIA, France: Hubert Gravel@inria.fr
CWI, The Netherlands: Wan Fokkink@cwi.ni

1.2. Research Consortium Award for Quantum Computing. *The Cor Baayen Award*[*] which is presented annually was created in 1995 to honour the first president of the European Consortium for Informatics and Mathematics (ECRIM)[**] is given for work on 'the potential computer of the future: the quantum computer'. It was awarded to a CWI[†] researcher Ronald de Wolf who, the citation said had:

> " . . . proved several limitations of this revolutionary computation model, He discovered new quantum algorithms that are more efficient than classical algorithms. Furthermore, he successfully applied quantum proof techniques on classical algorithms".

The award is given to the most promising young researcher who has completed his doctoral thesis in computer science and applied mathematics in one of the ECRIM countries.

Quantum information processing is not only new but also an important new field that combines the physical laws of quantum mechanics with those of computation, resulting in the new model of computation: the quantum computer. This is a field that gained momentum when Peter Shor demonstrated the speed with which such quantum computers could factor large numbers.

Most current cryptography, included in electronic commerce, is based on the fact that no sufficiently fast factorisation method is known to classical computers. Shor thus demonstrated that if one could build a quantum computer then most of our cryptographic protocols could be broken. In consequence, the importance and relevance of this work showed the potential of quantum information processing. As a result, research agencies, particularly in the USA and Europe have funded large amounts of money for investment in this new technology. Ronald de Wolf's work has carried on these developments and it has had a big impact on the field of quantum information processing. The citation of the award gives an indication of these achievments. *ERCIM. News* (No. 56. pp. 5–6, 2004) in an article on the possibilities and limitations of Quantum Computing whish has been published recently says that:

> "de Wolf also contributed to the discovery of some quantum algorithms and protocols that outperform their classical counterparts. One example of this is a 'quantum fingerprinting' scheme. It allows two separated parties to compare large chunks of data more efficiently than classical computers. By assigning small quantum states to long classical strings, the amount of data that has to be exchanged for this operation can be exponentially reduced. In the future this technique could for example be used to create digital autographs".

In 2001 de Wolf moved to the university at Berkeley USA. He worked there with Iordanis Kerenides and showed that quantum computing techniques could be used as a tool to prove new results in classi-computer science. In particular, they analyzed 2-query locally decodable error-correcting codes. This scheme allows each encoded bit to be individually decoded by looking at only two bits of the codeword instead

[*] More information about the Cor Baayen Awards can be found on: http://www.ercim.org/activity/cor-baayen.htmi

[**] ERCIM-The European Research Consortium for Informatics and Mathematics is an organisation dedicated to the advancement of European research and development in information technology and applied mathematics. Its national member institutions aim to foster collaborative work within the European research community and to increase co-operation with European industry. It is the European Host of the World Wide Web Consortium. Contact for information: www.ercim.org

[†] CWI – Centrum voor Wiskunde en informatica Kruislaan 413, NL-1098 SJ Amsterdam, The Netherlands. Contact: http://www.cwi.nl/

https://doi.org/10.1017/S026357470400116X Published online by Cambridge University Press

of decoding the entire codeword. The description of the award winner's researchers says that such:

> "locally decodable codes have been the focus of much research recently, but the previous best general lower bounds on their length were only polynomial. Using techniques from quantum computing, Kerenidis and de Wolf established for the first time an exponential lower bound. No proof of this result is known that uses just classical proof techniques".

This research has highlighted that we do not need to build a quantum computer to appreciate the contribution quantum techniques can make.

Commenting on de Wolf's work experts in the field have agreed and believe that;

> "This classical-theorem-with-a-quantum-proof significantly adds to the relevance of quantum computing within computer science in general, since its impact does not depend on the actual building of a quantum computer. As a bonus, the quantum techniques yield quantum protocols for the cryptographic task of 'private information retrieval' that are more efficient than the best known classical protocols".

Currently, researches in quantum computing continue at CWI and, indeed at many other universities and organisations. Dr. de Wolf has as his main research focus, research and development of quantum computing at CWI. Further information about his work and CWI research, can be found on: http://homepages, cwi.nl/ - rdewolf and also by contacting e-mail: rdwolf@cwi.ni

2. United states

Driverless Rolling Robot Race. The chance to win a $1 million contract proved to be an enormous incentive to robotics research teams who had been challenged to build driverless robots for a race across the Mojave Desert.

The US Department of Defence Advanced Research Projects Agency had offered the prize to the competing team that was the first robotic vehicle to complete the Grand Challenge. This was to race over some 142 miles of desert situated outside Los Angeles to a point near to Las Vegas. No vehicles, however, came close to taking the winning award. The event's first top finisher was a Humvee which had been remodelled by a team from Carnegie Melon University. It had travelled just over seven miles before it suddenly left its path and ended up with a broken axle. The Carnegie team, known as the Red Team, was led by Professor William L. Whittaker. Although this team effort produced a robot that only got within 130 miles of the finish 1line we are told by Dr. Whittaker that:

> "The key to the Red Team's relative success was its mapping system. All the entrants used navigational technology to allow their robots to manoeuver without being directed by human hands but the Carnegie Mellon system was considered the most advanced".

Entrants were not allowed to touch or steer their robots, and they received a map of the course only two hours before the competition started. The REd Teams robot, it was claimed, was not running at 100% and the actual desert terrain proved too tricky. Twenty-five teams took part, with seven of them led by University Professors, all chosen from a larger pool of applicants by the defence agency.

It is reported that Carnegie spent more than $300,000 of its own money on their entry but donations from companies like Boeing, Intel and Alocoa allowed this to be increased to a spend of some $3 million on the project.

The US Defence Agency had, itself, invested some $13 million in the race which, even without a winner, was declared 'a success'.

With such monies at stake readers will undoubtedly be intrigued why such an investment was made. Maybe the organisers have a hidden agenda? The department of defence simply says 'Our goal is just to push this technology forward by challenging it'. As a result, they are already organising a sequel for 2005 giving teams plenty of time to develop their robot entries. There is no doubt that such challenges can spur researchers to greater efforts and robotics will be the ultimate winner.

AUTOMATED SMELL SENSORS

The development of new smell technology allows the automated identification of smell. Several reports have already descibed the Artificial Nose which has been developed at Manchester University UK., and also by researchers at other establishments worldwide. Publicity has highlighted some of the applications of the artificial nose with examples of its use in the search for truffles, sensing semtex, in the wine industry and more recently in the diagnosis of disease. Any artificial nose could work automatically and could easily be installed in a robotic system giving to the robot yet another human attribute.

1. UK initiatives

The UK Government scientists are now said to be developing these technologies to allow for identification by body odour. The immediate aim is to use it to trace criminals by their unique odour. Biometric technologies which use the body as a password are becoming of increasing importance. These developing technologies already include face recognition, analysis of hand and finger geometry, voice patterns, and with retina patterns already becoming a popular means of identification. In addition gait, ear-shape, skull resonance and now body odour. Many other possible features of the human body have also been researched.

Smell is seen by security researchers as having great potential. Each person produces an odour with a different chemical formula. Apparently, we are told, we smell all the time even if the smell is undetectable to the human nose. A report on the use of smell recently published says that:

> Our odour is largely produced by the bacteria on our skin and our pheromones, the chemical we produce to signal to others of the same species. The great advantage for law enforcement is that, however hard we scrub or cover ourselves in deodorant, we cannot entirely obscure our 'sniff signature'.

2. Current devices

Researchers have developed a number of different odour detectors that analyse human smell. The process of their

https://doi.org/10.1017/S026357470400116X Published online by Cambridge University Press

evaluation continues. The study of the degradation of human bacterial cell culture on the skin is therefore a subject of much interest.

Current devices are described by developers, as

> "Most depend on users holding the palm of their hand against a sensor that can recognise the unique scent-once it has been broken down into a complex algorithm. When an individual's body odour has been registered, it could be entered on an identity card or on a passport".

It is reported that the aim is to achieve a system of odour identification that would allow the identification of an individ-in a crowd. Even an attempt to build a data bank of smells has been seriously considered. If such devices are successful they will compete with the growing number of other recognition systems that are coming into use. Many of these systems can also be used as part of an automated recognition system, where the addition of another 'sense' will be particularly attractive.

3. 'e-nose' developments in the UK and Italy

Whether robotic doctors are the figment of a sci-fi writer still remains to be seen, but the new artificial noses are now set to play a part in medical diagnosis and in other applications.

Smell, as well as providing us with unique identification features, has also been used as a diagnostic tool for many centuries. We are told in one report on the subject that the Romans gave distinctive odour of renal failure its own name 'fetor hepaticus'. In addition, a 'sweet acetone' breath suggests diabetes, whilst a 'putrid' breath' streptococcal throat infections.

A recent report looks at the way in which this has been harnessed to diagnose disease.

> ". . . . . , researchers at the University of Rome have designed an electronic nose ("e-nose") for detecting lung cancer in patients. In recent trials at the Forlanini Hospital, the e-nose correctly identified patients with lung cancer tumours simply by smelling their breath.
>
> E-noses have been employed by the food industry for about ten years and are used for many tasks, from detecting *e.coli* in contaminated food to verifying that orange juice is "natural" (important for food trading standards purposes as well as for the food buyers)".

The report from the University of Rome indicates that like some other artificial noses, its device is a chemical sensing machine. In fact, it is a spectrometer linked to a computer system that is programmed to match the patterns made by smells. It is therefore necessary to have an algorithm that uses a pattern store of smells and the necessary software to use it. This means the machine can be 'trained' to pick up certain smell signatures which are themselves a mix or combination of smells.

The theory behind these diagnostic systems is that like the Romans we can detect particular smells that are associated with diseases. For example, we are informed by the researchers that people with lung cancer tend to exhale a mixture of alkanes and benzene derivatives. Artificial noses can be programmed to pick up these traces and in the case of the University of Rome's device, lung cancer patients were diagnosed in one minute.

Obviously; if the e-noses were based on human noses then their capacity would be limited instead, an olfactory model of a dog's nose is used. A dog has well-known powers of smell and it is estimated to be several million times more sensitive than humans.

There are many cases already of dogs sniffing out human disease that have been reported in this section. Many of these instances of canine disease diagnosis can be emulated by the e-nose. Dogs, say researchers, can spot certain cancers and the Cambridge University (UK) Department of Clinical Veterinary Medicine is testing the viability of using dogs to sniff out prostate cancer in urine samples. Other diseases produce chemical signatures and the use of the e-nose to diagnose diabetes, liver cirrhosis and renal disease all appear to be possible.

A word of caution comes from the University of Rome research team who say that such devices may well have their limitations. For example, alkanes and benzene derivatives occur at such low levels in human breath that the sensors, which are usually a matrix of quartz crystals with a particular coating, need to be very precisely tuned to produce accurate results. They also suggest that the accuracy may be reduced because the sensor's performance fluctuates in time. There are, ofcourse, many groups working throughout the world to remedy these problems and their enthusiasm to produce a viable e-nose does not appear to have been dented. For further information see: www.nose-network.org

4. Transmitting smell electronically

Sending smell by e-mail is now, it would appear, a serious possibility. It is one of the senses that it has always been sought by the designers of human-interface systems. Although other senses were made available, the ability to include smell by some electronic means seemed impossible.

A recent report, however, outlines the initiatives of the company – Telewest Broadband which has commenced trials of a new web technology which will they claim, bring the third sense into play on the internet. This it would appear, if successful, will allow people to aromatise their communications with smell of their own choice, the company reports. It also has far reaching effects on the development of interfaces of all descriptions. The missing sense can be simulated in e-mails in particular. In future we are told the smell of baking, flowers, the countryside and many more evocative odours can be received on our terminals worldwide.

INNOVATIVE SYSTEMS

1. Automated health systems

The IBM Zurich Research Laboratory* has outlined the work of IBM researchers who are working with medical device manufacturers and mobile-phone handset manufacturers to provide a method of tracking vital health signs. They believe that they have a unique solution to the problem and that their technology, if adopted, could help limit a patient's health risk. At the same time they say their solution would increase the patient's comfort, reduce both the number of checkups and

* See- : http://www.zurich.ibm.com/csc/mobile/index.html

https://doi.org/10.1017/S026357470400116X Published online by Cambridge University Press

the time spent in hospital and also increase the effect iveness of pharmaceutical field tests. The solution is said to include a 'pill-box' and a home-based blood pressure monitor that resembles a large wrist watch.

Dirk Husemann of the IBM Research Laboratory writes that:

> "These new prototypes build on existing devices available through specialist suppliers and diagnostics companies. The new enhancements make it possible for the devices to transmit secure patient data, free of tampering, through a mobile phone to an Internet portal and so to the doctors and nurses monitoring the patient. The wristband blood-pressure monitoring device can also check other vital signs such as heart rate, and is activated by simply pressing a button. Blood-pressure readings, for example, are gathered from one or more sensors via a Bluetooth short-range radio connection. Once transmitted, secure access ensures only authorised medical personnel see the patient's data. If an unusual reading comes through, either a reminder can be sent to the patient to take his or her medication or a new prescription can be made, depending on the doctor's diagnosis".

The 'pill box' facility helps keep track of the patient's medication by sending a signal to his or her mobile phone every time a pill is removed, If a patient forgets to take medication or is taking too many pills, he or she is sent a reminder via mobile phone to follow the prescribed dosage.

One important outcome of the development of such systems is that it provides a degree of automation to what previously was a very 'hit or miss' arrangement between the medical carer and patient.

One other advantage, we are told, is that since vital measurements are taken so easily and can be monitored 'on-the-go' the system is expected to increase patient mobility, and, ofcourse, reduce the need for the patient to visit the doctor. There is also a psychological impact on the patient who feels that he or she is being constantly checked and monitored by carers. This is particularly important, the systems developers say, when people suffer from a chronic illness or are recovering from an operation.

One other 'spinoff' from this system is the use that the pharmaceutical industry will be able to make of it. Field trials, for example could now be conducted in a much more precise way. Biocyberneticians see this system as one that has taken advantage of the emerging technology that is available from the information-based medicine field. It has now been applied in real time to real problems involved in patient care.

2. Humans become mobile-cell phones

A report from the Japanese company NTT DoCoMo, regarded as that country's largest mobile telecoms company, gives details of a wearable mobile phone that uses the human body to make calls. The innovative development is called 'Finger and Whisper' and is a device which is built into a narrow strap that can be worn on the wrist like an ordinary watch.

Its function is very simple. To make or receive a call the phone user merely touches the forefinger to the thumb and then puts their forefinger in their ear, the report tells us. The company say that the electronics in the wristband convert sound waves into vibrations, which are then carried through the bones of the hand to the ear so that the phone user can hear a caller. What is surprising is the claim that because bones are able to transmit vibrations better than air the sound quality should be superior to the conventional cell phone. It should also filter out with little trouble, any background noises that may interfere with the call.

As to dialling a number the developers say that a microphone in the wristband has replaced the conventional phone mouthpiece, and instead of dialling a number, the phone user says it out loud.

It then relies on voice recognition technology to transform the sounds of the command into the required dialled number. Researchers at the company have also plans to refine the system so that the sounds of the user's voice would be received directly from the muscles around the mouth. These movements would then be translated into a dialled number. To do this, we are told, the phone user would need to wear ring-shaped detector electrodes on their thumb, forefinger, and middle finger and place them on their cheek and upper lip so the myoelectric signals generated by the mouth's muscle cells can be picked up.

NTT DoCoMo researchers claim that progress in developing the mouth muscle movement detector has been promising. Already vowels used by the phone user can be identified and now they are concentrating on discerning consonants. These are apparently more difficult to detect since they involve more complex muscle action and also they tend to be spoken much more quickly than vowels.

Further developments could involve the use of brain waves which could be analysed for dialling purposes and for other applications. Advances in the development of 'brain wave' transfers have already been featured in this Section. A more optimistic view of the use of an analysis of brain waves for such an innovative device has been published by Japanese newspaper *Nikkei Weekly* of Tokyo. We have yet to be given a date for the marketing of the Finger Whisper device. The company is also engaged in producing other innovative phones which, we are told, are superior to the recently marketed video phones.

The prospects, it would seem, are good for such developments which are also research projects currently being carried out by many manufacturing research groups.

MACHINE INTELLIGENCE

1. Research award for machine intelligence

An award for progress towards machine intelligence was instituted in 2002 by the Artificial Intelligence Special Group of the British Computer Society (BCS), U.K. The winner for 2003 was a robot developed by a team from Sunderland University, UK., which was led by Cornelius Weber. The team produced a robot which is able to recognise an object and then pick it up from a table. This project competed with four other universities to gain the award.

The robot is called MIRA. It is fitted with cameras and sonar devices. It demonstrated during the competition its ability to respond to a verbal command, move independently towards a table identify an object, to grasp it, move back to its original location and on a second command to release it from its grip. As an example of its versatility it showed,

https://doi.org/10.1017/S026357470400116X Published online by Cambridge University Press

after receiving a command, how it could recognise an orange, remove it from a table and take it back to where it started and then relax its grip on it when prompted. It was encouraging to read the award panel's comment on the entries that whilst:

> "MIRA represents a real step forward in robot technology and machine intelligence and provides a foundation for some future applications in both domestic and commercial robots".

it was considered that overall the quality of all 2003 entrants was very good. The panel chairman Max Bramer believes that:

> "All the finalists clearly demonstrated that machine intelligence is an area where much progress is being made in terms of abstract thinking and exciting, in terms of actual implementation"

Although the award is run by the Artificial Intelligence Specialist Group, it receives the support of the Applied Knowledge Research Institute and is sponsored by the Electrolux Group. Emtrants have been invited to compete for the 2004 Award. Further details can be found on: www.bcs=sgai/org2003/miprize

2. A 'Robotic Scientist' that can formulate theories?
Scientists at the University of Wales at Aberystwyth (U.K.) have created a Robot Scientist that can formulate theories, perform experiments and interpret results. The claim was made in a recent issue of the scientific journal *Nature*.

The team of researchers reports that although the Robot Scientist is not as intelligent as, for example, a leading chess playing computer, it does combine the 'intelligence' of a computer with the agility to tackle a real scientific problem. This would be an important breakthrough and, indeed, a major engineering feat.

It is reported that in a recent test against human competitors the robot worked out which genes in yeast are responsible for making vital amino acids. It is claimed that it was even faster at completing this task than a recognised biologist, who we are told, says that he hit the wrong key at one stage in his solution. It also seems that the robot scientist has a financial aptitude inasmuch as it appeared to be more sensitive to financial concerns. This is in contrast to human competitors who were penalised in the tests for overspending.

The design of a machine that can in reality compete with a human's 'brain-power' requires not only more hardware but the ability to organise it. Scientists worldwide know that since the early days of computers there have been great advances in the development of both hardware and software. Whereas Von Neumann's estimate of the human brain's storage capacity at 35 million megabytes with later estimates leading to figures of 40 million and more, the computing machines of the late 1950s had very little storage. These early machines which had memories measured in units of 1k or less appeared to be no competitor to the human beings mental prowess. Now, however, the currently produced PCs have more storage than the latest assessments of the data the human brain can store over a lifetime. This is, of course, only one indication that there has been a substantial development of systems that could be designed and built to compete with the human brain. We need the skills and ability of the human to design and to build such devices with the hardware and software systems that are already at our disposal.

QUESTIONING AND ANALYSING DATA

1. Capturing robotics data and its analysis: Questions and answers based on the latest robotics information
Getting the latest data about trends in the robot world is no different from that of attempting to survey activity in other sections of the world's complex developments. Although business quarterly returns give us an indication of current trends even the futures markets of the world are not capable of forecasting with much confidence.

For some degree of accuracy in our assessments we need reliable data and in the robotics and automation industries it is often better to rely on a responsible data-collection and analysis organisation, and preferably one without any bias.

Data on robotics, apart from quarterly or half-yearly results is almost invariably a year old. Currently, we rely on our annual statistics for the year 2002, and forecasts are made for 2003 and beyond. Of the various groups who carry out the data capture for world robotics and also conduct an analysis, undoubtedly the United Nations Economic Commission for Europe (UNECE), working in cooperation with the International Federation of Robotics (IFR) produce one of the most reliable and comprehensive in-depth publications. World Robotics 2003* will soon be updated once again but is, at present, based on the 2002 and pre-2002 annual information.

2. Asking the questions and having confidence in the answers
This current publication is able to include comment based on the first half of 2003 and is able to assess and forecast both results and trends, which although not necessarily those of 2004/5 provide a valuable source of information. Some of the following questions and answers illustrate this analysis:

- **Is Japan's lead position in automation eroding?** Robot business was booming in Japan in the 1980s and early 1990s. The optimism was unlimited. It seemed as if everything that could be robotized was robotized. Since the middle of the 1990s, the momentum in the robot business has moved to Europe and North America. In 2002, the robot stock increased by 6% in both regions. In Japan it has steadily been falling since 1998.
- **Why invest in robots?** In the last decade the performance of robots has increased enormously while at the same time their prices have been plummeting. A robot sold in 2002 would have cost less than a fifth of what a robot with the same performance would have cost in 1990. In the last few years the price decrease of robots has, however, started to level off. Profitability studies have shown that it is not unusual for robots to have a pay-back period as short as 1–2 years.

* Source : UNECE and IFR data published by UNECE Information CH-1211, Geneva 10 based on the UNECE summary of its publication World Robotics 2003, and 2003/4 quarterly companies releases and forecasts to 2006.

https://doi.org/10.1017/S026357470400116X Published online by Cambridge University Press

- **And not hire people?** In Germany, for instance, the prices of robots relative to labour costs have fallen from 100 in 1990 to 34 in 2002 and to 17 when taking into account the radically improved performance of robots. In North America, the relative price dropped to 24 and to about 12 if quality improvements are taken into consideration. "*Falling or stable robot prices, increasing labour costs and continuously improved technology are major driving forces which speak for continued massive robot investment in industry*", concludes Jan Karisson. Even in developing countries like Brazil, Mexico and China, robot investments are starting to take off at an impressive rate.
- **If robots are so profitable why is there not an even stronger rush to invest?** Robots are not products to be acquired "over the counter". In order to reap the benefits of robots, potential user companies must have sufficient in-house technological know-how as well as a thorough comprehension of their production processes.
- **How did the economic slow-down in 2002 affect the robot business?** '*The world market fell by 12% as a result of falling demand in all major markets. However, robots did much better than many other similar types of investment goods. Machine tools, for instance, fell in major markets three times as much as robots*, says Jan Karisson, responsible for the UNECE/IFR publication. The robot market in the United States fell by 8%, by close to 11% in Japan and by 16% in the European Union. The drop in the European Union market should, however, be seen in the light of the fact that with the exception of 1997, when the market fell by 1%, the European Union has had market growth since 1994 and, except for 2001, double digit-growth.
- **What about the trends in 2003 and the forecast for 2003–2006?** The UNECE/IFR quarterly survey on order intake of industrial robots, which includes most of the world's largest companies, showed that worldwide order intake increased by 26%, compared with the same period in 2002. It was the highest order intake of industrial robots ever recorded, worldwide and in all regions, except in North America where it was the third best half year recorded. The order intake, by regions, of industrial robots during the first half of 2003, compared with the same period in 2002, was as follows:

  North America +35%, Europe +25%,
  Asia +18%, Other regions +19%

  These figures indicate that a strong recovery is in sight in the investment propensity in industry. The results for the first half of 2003 point to total sales of over 80,000 robots in 2003, compared with 68,600 in 2002.
- **How many robots are now working out there in industry?** Worldwide at least 770,000 units (possibly the real stock could be well over one million units), of which 350,000 in Japan, 233,000 in the European Union and about 104,000 in North America. In Europe, Germany is in the lead with just under 105,000 units, followed by Italy with 47,000, France with 24,000, Spain with 18,000 and the United Kingdom with 14,000.
- **What is the forecast for 2005?** A conservative forecast points to some 875,000 units worldwide, of which 333,000 in Japan, 303,000 in the European Union and 135,000 in North America.
- **How many robots per employee in the manufacturing industry?** About 310 per 10,000 employees in Japan, 135 in Germany, 109 in Italy, 91 in Sweden and between 50 and 70 in Finland, France, Spain, Benelux and the United States (the figure for Japan includes all types of robots while for all the other countries only multipurpose industrial robots are included. The figures are therefore not comparable).
- **In the car industry?** In Japan, Italy and Germany there is more than 1 robot per 10 production workers.
- **Are we seeing any service robots in our homes?** At the end of 2002 more than 50,000 autonomous vacuum cleaners and lawn-mowing robots were in operation. By the end of 2006, a tenfold increase is predicted.
- **How are service robots for professional use doing?** Medical robots, underwater robots, surveillance robots, demolition robots and many other types of robots for carrying out a multitude of tasks are doing very well. A stock of some 19,000 units was estimated at the end of 2002. In the period 2003–2006, another 30,000 units are projected to be added to the stock.

RESCUE ROBOTICS

1. Application of robotics to security challenges

An article by Robin R. Murphy: "Rescue Robotics for Homeland Security" published in *Communications of the ACM* **47**(3) pp. 66–8 (2004) discusses the application of hard-earned lessons gained from recent disasters. This, he believes, has led to the improvement of information gathering and human-robot interaction.

The current attention is partly, he writes, in response to the use of rescue robots at the site of the collapse of the World Trade Center (WTC) towers in New York. This response was an example of an urban search and rescue (USAR) mission. USAR deals with man-made structures and has a different emphasis than, for example, the traditional wilderness search and rescue, or underwater recovery efforts. They can be even more demanding on robot hardware and software than equivalent military operations we are informed.

Robin Murphy, who is the Director of the *Center for Robot-Assisted Search and Rescue* at the *University of South Florida*, USA, has published a number of papers on USAR (see; *Robotics and Automation* magazine, June 2004) and also with other researchers (see: *AI magazine, January 2002*, and the *IEEE Transactions on Systems*, January 2003). At the WTC from Sept 11-Oct. 2 2001 robots were used to search for victims and to help assess the structural integrity of the foundations. The teams of robot-assisted searchers and rescuers operated small robots, some Dr Murphy says were small enough to fit into backpacks, He writes that:

> "The robots were used for tasks that rescuers or canines could not perform, for example, to either go into spaces that are too small for a human or to pass through an area on fire or without breathing air in an attempt to reach a survivable void".

A particular application at the WTC site involved the use of the Inuktun micro-VGTV robot, in an attempt tolocate an entry into a basement it was inserted into a sewer pipe.

https://doi.org/10.1017/S026357470400116X Published online by Cambridge University Press

The Inuktun micro robot is described as being:

> "A small sized robot and was inserted into the sewer pipe using a tether as a safety line for the vertical entry needed for the operation. A camcorder was used to display the video because of its better resolution than the manufacturer's display".

As a result of the WTC mission and the expertise of both researchers and users, many new research areas and issues have been identified. These include:

a. "The physical attributes of the robots used require improvements e. g lack of sensors that can be mounted on the robots.
b. Communications-Micro-sized robots require a tethered connection back to the power and control source. Even wireless robots which are larger and more mobile require a safety line-they can easily be lost in dense rubble.
c. Robots need to be 'hardened' because of their use as a result of chemical, biological or radiological events.
d. Human endeavour-robots and agents will act in concert with a spectrum of trained professionals, cognitively and physically fatigued individuals, motivated volunteers and frightened victims. Good human-robot interaction (HRI) is critical to success and acceptance of the systems".

Further information from the *Center for Robot-Assisted Search and Rescue*, *University of South Florida* and the Center Director at murphy@csee.usf.edu.

ROBOTIC AIRCRAFT

Advances in research involved with the production of robotic aircraft have now, inevitiably led to the development of insect-sized machines. We are now told that the rate of progress has been so great that we can expect working models in the next year.

Research is being funded by the US Air Force and by BAE Systems and micro-planes the size of insects are planned.

One team developing such, a devies, at Bath University UK., has been studying bees and dragon flies so that they can assess whether researchers can develop flappable wings for tiny aircraft.

If this proves viable they could be used for industrial or military surveillance. Ismet Gursel, the Head of aerospace at the university's mechanical engineering department reports that the miniature drones would include cameras and computers. He says that:

> "The miniaturisation of computer hardware and software is already far more advanced than micro aircraft. Tracking devices smaller than a grain of sand have already been developed".

The government of the UK, the BAE, and the US Air Forces are supporting the project by contributing £650,000 towards the research at Bath. There is still some discussion about what applications would result from this development. Quite obviously, the micro-planes would be useful for detecting chemical or biological weapons and other military uses such as landing on enemy vehicles and for reconnaissance work. Many other applications, particularly in a industrial espionage and other surveillance operations will be developed. Bath University researchers suggest that such drones could be used to conduct safety checks inside nuclear reactors or could be flown inside gas pipelines. A report on the current progress tells us that:

> "The most important step is to overcome the aerodynamic challenges. Rapid flapping is regarded by researchers as is the most efficient way to fly but we are also studying squid which emit puffs of fluid to move along. We hope to start with a drone about 15 cms. long and weighing 50 gms. and capable of flying for an hour. Something the size of a bee is within grasp but the smaller an aircraft is made, the slower is its speed and the more vulnerable it is to high winds. We are confident that this research will overcome these problems".

Dr Gursul also reports that the Bath University research is breaking new ground. He says that:

> ". . . . . While naturalists have studied bird and insect flight for more than half a century, our basic knowledge of their aerodynamics is limited.
>
> "The scientific knowledge of aircraft flight does not apply easily on a small scale and scientists do not have a full understanding of the stamina of a bee or the agility of a dragonly",

Other researchers worldwide are working on similar lines and are intent on producing micro-aircraft. Not only is research required into the aerodynamical problems associated with the projects but also the necessary nanotechnological techniques needed to construct these insect-sized micro-planes.

WORLD ROBOTICS AND AUTOMATION TRENDS

1. Estimating the worldwide operational stock of industrial robots

As we have noted earlier in this issue it is extremely difficult to gauge the actual operational stock of robots worldwide. Apart from agreeing on what constitutes an acceptable definition of a robot or, indeed, an automated system it is necessary to capture the data from countries worldwide.

The reliability of data submitted by individual countries and its subsequent analysis, can produce a false basis for predieting future trends.

If the basis for forecasting is that produced by the UNECE and the IFR* we are informed that the total accumulated yearly sales, measured since industrial robots started to be introduced into industry at the end of the 1960s, amounted at the end of 2002, to some 1,328,000 units. This includes the dedicated industrial robots installed in Japan up to and including 2000.

Obviously many of the early robots have been taken out of service. A reasonable estimate based on this information prepared by UNECE and IFR assesses the total worldwide stock of operational industrial robots at the end of 2002 as between 770,000 and 1,050,000 units. It is pointed out that the lower figure is based on the assumption that the average

* UNECE. –*United Nations Economic Commission for Europe* (Information Service: CH-1211 Geneva 10 Switzerland) E-mail: info.ece@unece.org
IFA – *International Federation of Robotics* (Statistic Dept., c/0 VDMA Robotics +Automation Lyoner Str. 18 D-60528 Frankfurt am Main, Germany) E-mail gudrun.litzenbergen@vdma.org.

https://doi.org/10.1017/S026357470400116X Published online by Cambridge University Press

Table I. *Multipurpose industrial robots in 2001/2 and* forecasts 2003–6. The number of units are given for both installations and operational stock.

	Yearly installations				Operational stock at year-end			
Country	2001	2002	2003	2006	2001	2002	2003	2006
Japan	28,369	25,373	27,300	33,900	361,232	350,169	344,000	333,400
United States	10,813	9,955	11,400	14,500	97,257	103,515	111,100	135,200
European Union	30,735	25,886	26,600	31,800	219,515	233,139	248,100	303,500
Other Europe	698	744	800	1,100	11,002	11,013	10,500	12,100
Asia/Australia	5,310	5,105	5,600	7,500	56,997	60,412	64,300	73,300
Other countries al	2,250	1,520	1,700	2,300	10,374	11,640	12,900	17,800
Subtotal, excl. Japan and Rep. of Korea	45,726	39,195	41,800	51,900	353,878	375,454	446,900	541,900
Total, including Japan and Rep. of Korea	78,175	68,566	73,400	91,100	756,377	769,888	833,400	875,300

Sources: UNENCE, IFR and national robot associations.
al/Estimated by UNECE and IFR for some or for all the years.
(Abbreviated table compiled from UNECE/IFR summary of World Robotics 2003).

service life is 12 years, whilst the higher figure is based on 15 years service.

2. Forecasts for 2003–2006

From the captured data base compiled by UNECE, IFR and the national robot associations, forecasts can be made from 2002 to 2006. We are told that on this basis the world market for industrial robots is projected to increase from 68,600 units in 2002 to just over 91,000 in 2006 or by a yearly average of 7.4%. Table I has been compiled to illustrate these forecasts.

Commenting on the steady growth in Europe and in North America the UNECE/IFR compilers of *World Robotics 2003* say that:

The robot market in the European Union is expected to grow from 25,900 units in 2002 to just under 32,000 units in 2006, representing an annual average growth of 5.3% whilst/in North America, the market is estimated to grow by an average annual rate of 9.9%, which implies that it will reach between 14,000 and 15,000 units in 2006. In view of a somewhat optimistic economic forecast by OECD of a recovery, these forecasts for robotics, mainly based on the opinions of robotics experts, might be somewhat too conservative.

The compilers also produce projections for 2003/6 installations of new service robots for professional use, as well as a forecast for service robots for personal use. They comment:

3. Projections for the period 2003–2006; 30,000 new service robots for professional use to be installed

Tuming to the projections for the period 2003–2006, the stock of service robots for professional use is forecasted to increase by some 30,000 units. Application areas with strong growth are medical robots with more than 6,000 new robots being added, surveillance and security robots (3,800), underwater robots (3,000), mobile robot platforms for multiple use (2,800), cleaning robots (1,700) and robotic systems for milking (1,450).

4. Projections for the period 2003–2006: over 2.1 million units of service robots for personal use to be sold

It is projected that sales of all types of domestic robots (vacuum cleaning, lawn-mowing, window cleaning and other types) in the period 2003–2006 can reach some 638,000 units.

Although this number excludes the too optimistic forecasts of several millions of units made by some companies, it might in the light of sales recorded already in 2003 be far too low.

The market for toy and entertainment robots is forecasted to exceed 1.5 million units, most of which, of course, are very low cost. One company expects sales of several millions of units within the next years.

The Team Leader of the *Economic Statistics UNECE Statistical Division* (Geneva, Switzerland) reminds readers that the *ECE/IFR Robotics Index* records quarterly order intake of industrial robots by region. This index, he says, is a timely indicator of the directions of robot investments by industry as well as the general business climate. It can be accessed at: *www.unece.org/stats/robotics*

Professor Brian H. Rudall
Norbert Wiener Institute and
University of Wales (UK).
Section Editor

https://doi.org/10.1017/S026357470400116X Published online by Cambridge University Press