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Reports and Surveys

I. ARTIFICIAL SKIN FOR ROBOTS

I.1. Organic transistors for artificial skin

Organic transistors have been developed to a state where, combined with pressure sensors, they may prepare the way for the development of an artificial skin that could be utilised by robots and in automation applications.

Although robots are already multitasking in so many different situations none of them has a sensitive artificial skin. This we are told, is mainly because silicon-based electronics have been found to be unsuitable for the flexible switching matrix that is required. Professor Takao Someya, from the Quantum-Phase Electronics Center, University of Tokyo (Japan), sees the future for such developments in organic circuitry. He believes these are both flexible and cheap and suggests that combining organic transistors with rubber pressure sensors paves the way to a 'practical artificial skin'. This initiative is discussed by Professor Someya and his colleagues in the *Proceedings of the National Academy of Science, USA* (101,27, 2004).

I.2. Research at the Quantum-Phase Electronics Centre

Dr Someya and his research team at the Quantum-Phase Electronic Centre, have developed a large-area pressure sensing device. It consists of a poly(ethylene naphthalate) base film which is coated with various polymer and metal layers and a pentacene layer which is to function as a series of transistors. Then a pressure-sensitive rubber sheet is laminated to the bottom of the base film.

Trials of the new device found that it could take 'pressure images' even when the sheet was bent, although it was reported that the gold transistors limited the amount that it could be deformed by. To further their experiment researchers tested the device using a rubber stamp molded in the shape of human lips. They reported rather humourously that:

> 'Even though the resolution of the present device is too low for the sensor to identify whose lips it is touching, the experience is conclusive enough to fuel one's imagination'.

In an interview with *Chemistry World* (August, 2004) Dr Someya said that he and his research group had already received 'lots of feedback' from various industries. He also is, apparently, not short of ideas. He explained how to use the new technology to develop carpets for the elderly which would contain sensors to detect whether a person has collapsed and then to monitor heart rates. The possibilities for such applications must surely be numerous and wide ranging.

I.3. Future research and development

The Japanese researchers believe that they could make the device more like human skin by increasing the density of the sensor cells and incorporating artificial sensors for temperature and humidity. Dr Someya and his fellow researchers are now working to improve the innovative product by:

- Improving the stability of the organic transistors.
- producing an artificial skin that can be used in real products.

The researchers are optimistic about their future progress and confident that it will be used in numerous different ways in some five years time. One important achievement would be the production of a robot with 'electronic skin' that is capable of a high degree of sensitivity.

II. AUTOMATION MARKET STATISTICS

Robot investment data from the UN Economic Commission for Europe, (UNECE).

II.1. Surveys of the robot market

The United Nations Economic Commission for Europe (UNECE), and the International Federation of Robotics (IFR) produce regular surveys of the robot market. In a current report sent to this journal. Jan Karlsson of the Statistical Division of UNECE says that:

> "Never before have so many orders for industrial robots been placed by the European, North American and Asian industries, pointing towards an acceleration in the drive to automate".

II.2. Worldwide orders for industrial robots

The survey informs us that:

> In 2004, worldwide orders for industrial robots were 20% higher than in 2003. In Asia (heavily dominated by Japan and the Republic of Korea but also by a rapidly increasing market in China) they surged by 43%. Thereafter followed North America with 23% and Europe with 5%. Never before have so many robots been ordered, worldwide as well as by the various regions.
>
> In North America first and third quarters (Q1 and Q3) 2004 both grew by 16% while preliminary figures for Q4 2004 shows a growth of 10%. In Europe, 2004 started out bad with a drop of 8% but growth picked up sharply in the following quarters. Q3 2004 recorded a growth of 22% while in Q4 it stopped at 9%. Asia showed impressive growth of over 40% in all quarters except Q3.

II.3. Non-automotive industry investments

The survey indicates that worldwide non-automative industries are increasing their orders and stepping-up their robot investments. The report compares the non-automative and the automative industries:

> Normally, it is the automotive industry that leads the drive to robotize. In 2004, however, there was a significant turn around. Worldwide non-automotive industries increased their orders with

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close to 42% while final automotive assembly increased by less than 1% and automotive components with 19%.

In North America and Asia, non-automotive industries increased their orders with as much as 7.1% and 42%, respectively. In Europe a growth of 22% was recorded in orders from the non-automotive industries, in contrast to the final assembly in the automotive industry, which recorded a decrease in robot orders of 11%.

II.4. New robots installed worldwide

At least 100,000 new robots will have been installed in 2004 is an estimated compiled by the UNECE. This is based on the record new orders placed in 2004. The breakdown for the estimate is given as:

- 31,100 in the European Union (15% more than in 2003 but only 1% over the previous record in 2001),
- 16,100 in North America (27% more than in 2003 and 24% of the previous record of year 2000); and
- 51,400 in Asia, mainly in Japan but with rapidly increasing number in China (22% over 2003).

II.5. Robotization surges

Robotization has been spurred on by plummeting robot prices, with the prices of robots falling rapidly relative to labour costs. This has been singled out as the central reason for the increase. This has been based on the statistics that show that

> prices of robots are falling rapidly relative to labour costs. Expressed in constant 1990 US$, **robot prices in year 2004 were on average 46% lower than in 1990**. At the same time today's robots have much higher performance than those produced in 1990 with respect to versatility, speed, accuracy, and above all computer power. Meantime-between-failure improved by over 200% and accuracy by close to 70%, just to take a few examples.
>
> A quality-adjusted price index, that is, an index in which consideration is taken to the continuous performance improvements, would therefore show an even higher price reduction. It is estimated that **a robot in year 2004 costs less than one fourth of a robot in 1990 with the same performance.**

II.6. Labour costs rising

Although the prices of robots have plummeted and quality has increased, labour costs have risen steadily. We are told that:

> In the OECD area, **labour compensation per employee in the business sector rose by over 100%** in the period 1990–2004. The prices of robots relative to labour compensation thus fell from 100 in 1990 to 27, when taking no consideration to performance improvements, and to 11 when calculating the effects of performance improvements.

Jan Karlsonn of the UNECE believes that:

> "Rapidly falling relative prices of robots paired with shrinking labour supply, in particular to the manufacturing sector, in the years ahead will spur continued high growth in robot investment". "We have only seen the first phase of the robotization drive, which has mainly focused on the automotive industry. The food industry and all other manufacturing industries as well as many non-manufacturing sectors, are as the year 2004 data clearly show, significantly stepping up their investment in robot systems".

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III. DISTRIBUTED COMPUTING

III.1. Mass computer initiative

Whilst those engaged in research and development have always contemplated the use of mass communication and the applications of computing machines in a wide range of areas, the possibility of some 100,000 PC users cooperating in a 'Screen-saver' weather trial could hardly have been predicted. This they did when they took part in what has been described as the 'largest-ever climate change' experiment.

The experiment was launched in the United Kingdom at the behest of science writers of the UK *Daily Telegraph*, in 2001. PC users were asked to take part by downloading a special screen saver to run a computer model designed by the British Meteorological Office to explore a vast range of climate change scenarios. In January 2005 the results were published by the newspaper and the scientific journal *Nature*. The verdict produced as a result of this great experiment shows that:

> ". . . . recent warming is man-made and that a doubling of greenhouse gas levels from their pre-industrial state could cause more than double the maximum temperature rise so far considered likely by the Inter-Governmental Panel on Climate Change.
>
> The first results from climateprediction.net show that average temperatures could eventually rise by up to 11C – albeit after a new global climate pattern has been established over several hundred years, even thousands of years – even if carbon dioxide levels in the atmosphere are limited to twice those found before the industrial revolution.
>
> Such levels of greenhouse gases are expected to be reached around the middle of this century unless deep cuts are made in their emissions."

In summary, the experiment predicts that greenhouse gases will have a much greater impact on climate change than previously thought and will lead to a 'dramatically different' future. The Screen saver trial predicted levels of green house gases that could mean that the icecaps are likely to melt and Britain will be some 10°C warmer. The effects on the rest of the world around the middle of the next century can be similarly predicted.

The experiment's chief scientist Dr. David Stainforth from Oxford University (U.K.) is reported as believing that:

> "Increased levels of green-house gases could have a much greater impact on climate than previously thought. We are facing a world in the future which is dramatically different."

This, it has been suggested, means that the 11°C warning which is almost double that seen so far in the geological record would have a much greater impact at higher latitudes such as the UK. Dr Stainforth gives the opinion that at

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high latitudes the average warming could be as much as 20°C with the U.K. in the teens. It has been pointed out, however, that the model, like any computer forecast, has many uncertainties. We are told, for example, that the team involved with the project is not able to work out which of the range of temperature rises is the most likely, save to say that rises under 1°C are highly unlikely. This enables them to rule out natural causes for recent warming and the potential errors in the modelling rise the bigger the predicted changes.

The project co-ordinator Dr David Frame is quoted as saying that;

> "The possibility of such high responses has profound implications. If the real world response were anywhere near the upper end of our range, even today's levels of greenhouse gases could already be dangerously high."

Whilst Dr Myles Allen of Oxford University, who helped to set up the experiment, said that the project could see a shift in the focus of discussions about greenhouse gas emissions from stabilising atmospheric levels to cutting them.

The project was funded by the UKs *National Environment Research Council* and at this time it is still encouraging schools, businesses, as well as individuals across the globe, to download the free climate prediction net software that incorporates the climate model and runs in the background when their computers lie idle. It functions so that the program runs through a climate scenario over a few days and then reports the results back to the research team at Oxford.

This is a excellent example of what our co-operation can achieve and also what great use can be made of the idle time available on most PC's. Further experiments, particularly those involving modelling systems, could well now materialise.

III.2. Distributed computing projects

There are several schemes being prepared that are modelled on SETI @ home which was originally used by the search for Extra-Terrestrial Intelligence to examine raw radio signals from space that would otherwise be impossible to process. A team of researchers from Oxford University (UK) were also using similar methods to screen chemical compounds for their potential use as drugs for treating leukaemia.

III.3. Einstein distributed computing initiative

It has been reported that thousands of UK computer-users will join the search for one of the most mysterious forces in the Universe this year (2005) as part of the celebrations for the centenary of Albert Einstein's greatest discoveries. The organisers of the project "Einstein @ home", will tap into the spare capacity of home and office computers to analyse data that could confirm the existence of gravitational waves that Einstein predicted in his general theory of relativity, but which have never been detected. This will be accomplished, they believe by:

> "downloading a simple screensaver featuring the most famous face in physics, computer-users can link to a global network that will sift raw results from two observatories hunting for the elusive waves.
>
> Whenever the computer is idle and the screensaver starts up, its processing power will be added to the gravitational wave hunt. The combined capacity of hundreds of thousands of small computers joined in this way is much greater than anything normally available to scientists."

This, of course, is not the only initiative that will be organised to mark the Einstein Year, but the "Einstein @ home" project is surely the most exciting. We are told the 'gravitational waves are a great discovery waiting to happen by experts in the field and initiating this project will give the public an opportunity to take part, and if the waves are found, to claim their share of the glory.

The Institute of Physics tells us that

> "You could, in theory, be the person to discover a gravity wave, if it's your computer that helps to track them down."

We are also reminded that the waves are ripples in the fabric of space and time produced by violent energetic events such as exploding supernovae.

These and other distributed computing initiatives will have an important role to play in our future endeavours and any scheme that utilises the spare capacity of our home and office computing systems is to be encouraged.

IV. HUMANS AND MACHINES

We are told that the 21st century will herald a time when humans and machines will have meaningful dialogues. This presents a great challenge and it is not a question of only interfacing machines, such as computers or automated devices to the human species. It is more a question of integrating the human and machine. The latest and developing technology is enabling us to do this. Such an integrated product has already been given the name Cyborg, defined some time ago in rather narrow limits of being a "human whose limitations have been extended by machine technology". This definition was coined before the technology had even been developed. Now with the advent of chip technology it is becoming a reality.

IV.1. Enhancing humans with microchips

Trails have already taken place worldwide so that we can gauge the possibility of enhancing human powers by impregnating the human body with microchips. Microchips once successfully implanted will not only allow humans to control the functions of their own body but also machines of almost any description. To do this the nervous system has to be linked to the chips and the brain's power of control through 'thought' harnessed. Examples have already been given in this section on many occasions of machines powered by thought alone.

The initial experiments allowed humans who had chip implants to perform tasks such as turning on the lights or switching on some domestic appliance using 'thought' alone. Electrical signals from the brain can be transmitted to a computer and a remote control device. This technology has already been tested with animals and now with humans so that a cursor on a computer screen can be controlled by

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'thought'. The benefits of such a system, particularly for the disabled whose everyday tasks could be made much easier, have been recognised worldwide by marketing companies. For example, the US biomedical company *Cyberkinetics*,* have carried out research trials of such systems under government approval. They are not only of interest to the biomedical communities but also for application, for example, in automation and robotics.

IV.2. Ethical and practical concerns

There has already been extensive discussion about the ethical and practical consequences of such developments. The public, a spokesman from Cyberkinetics remarks, "will be afraid of machines that appear to read their minds". The company say:

> "There are other questions, too, such as making sure the chip interprets the right signal from a mass of electronic and chemical signals that it will be picking up in the brain. We want the person to be in control, not the computer, so there will be safeguards against the computer getting it wrong."

Cyberkinetics is carrying out trials with five quadriplegics. Each one will have a 4 mm silicon wafer laid on the surface of their front cortex. This is the part of the brain that controls movements. This differs from other trials described in the literature. These were neutral implants such as chips that can transmit electrical pulses into the brain (e.g. calm Parkinson's disease tremors). The new device is called BrainGate and is designed to read what is happening in this part of the brain.

The functions of BrainGate were described by the makers as:

> "Each action, such as lifting a finger, has a distinct pattern of electronic pulses. The chip detects and amplifies the signals and sends them down a cord leading through a hole above the left ear to a videotape-size "descrambler box" which translates them and relays them to a computer.
>
> In the trial, the computer will activate devices such as kettles, light switches and telephones by remote control. About 100 different functions will be tried.
>
> In the future, when the descrambler is reduced in size to a pack of cards and connected to the computer without wires, the system is intended to be tailored to each user's needs."

This advance into reading the brain's electrical impulses rather than using implants that transmit signals to the brain could be a breakthrough in linking the brain to the outside world. If successful it would mean that:

- a chip placed on the brain will enable a human to perform everyday tasks by thought alone.
- The electrical brain signals, that are unique to a human that have been 'thought' and linked to specific actions will be 'read' by the chip.
- Such 'thoughts' can be transmitted to a computing device which will recognise and match the appropriate action(s) and finally performing the chosen task.

* Cyberkinetics, Foxborough, MASS (USA).

IV.3. Marketing the new technology

We have already seen the marketing of devices that can turn a human into a cyborg. New devices with different technology are now undergoing trials. Whilst the methods of linking implanted devices to the functions of the human body may vary, they will most certainly improve in the future. The potential benefits are enormous and this could well be the century of the cyborgs.

V. INNOVATIONS

V.1. Robots perform multifunctional tasks in UK hospital

Robots called Sister Mary and Dr. Robbie have started work at St. Mary's Hospital, Paddington, West London (UK). The robots are 5 ft. tall and are controlled remotely. The robots have the capability of allowing specialists from anywhere in the world, to see, examine and speak to patients. This allows a dialogue between the patient and contacting medical advisors. who can also access, remotely, relevant medical records. The robots have been programmed so that they can remotely monitor any relevant information required, such as a patient's medical records, and to monitor X-rays and test results. This is a fascinating project and reports of their operation in hospital conditions and carrying out such onerous tasks is awaited by the UK's National Health Service (NHS).

V.2. First kidney transplant in UK robot-assisted operation

The £1 million Da Vinci robot at Guy's Hospital, London UK., has helped to remove a kidney and transplant a donor organ for the first time in Britain. Although the robot has already been used to remove diseased organs and carry out advanced reconstructive surgery it has not been used in a keyhole surgery operation for an organ transplant.

A report of the operation describes how two pencil-thin robot arms were inserted through 8 mm holes in the patient's body, their 'delicate 'hands' wielded surgical tools, snipped and sewed in response to finger and wrist movements made by an operator at a console a few feet away. The mechanical movements of the arms were said to be slower than those of the surgeons hand, but the device compensated by working without a tremor.

A third arm passed through another hole carrying a miniature camera. Images from the camera were then viewed in 3D by the operating surgeon. He examined the images by using a pair of "binoculars" and was able to control the position of the camera by using footpedals.

The Da Vinci robot was developed in the United States and currently there are two working at UK hospitals.

V.3. Developing Brain Fingerprints

It is reported that the U.S Government has provided substantial backing to the company *Brain Fingerprinting Laboratories* (USA). The laboratories are the initiative of Lawrence Farwell who it is claimed is the inventor of brain fingerprinting. The company he owns has been set up to market the technique and conduct further investigations into its development as a viable system which, if successful, has enormous potential. The technique, at this stage of

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development, is not without its critics who have published their views in the scientific journal *Nature*.

Farwell has briefly described his technique. He says that people remember major events in their life and that tends to have a solid record in the brain. The technique for harnessing this characteristic is described as:

> "Unlike discredited lie-detecting techniques, which measure changes in breathing, heart rate and other variables to determine if suspects are trying to deceive their interrogators, brain fingerprinting is designed to discover if specific information is stored in a person's brain. The technique exploits the fact that the brain emits an electrical signal known as a P300 exactly 300 milliseconds after it is confronted with a stimulus that has special significance to that individual – for example, a victim's face.
>
> The fundamental difference between the perpetrator of a crime and an innocent person is that the former has the details of it stored in his brain.' "The innocent suspect does not."

An example of the use of the technique illustrates that, for example, a robber will indvertently emit a P300 signal, which can then be picked up using electrodes fitted to his skull, when in this case an image of say the victim or the gun used is displayed. Such a signal, we are told is not emitted by an innocent person.

The technique has been under trial and it is claimed that there has been total success. Farwell quotes a number of cases where he has worked with FBI agents. He believes the technique could have vital criminal and security uses and there are a great number of applications in the current world climate. The system works in such a way that it can be easily used by non-scientists. For example, the stages would be

- Suspect is wired with an electrode 'cap' placed over the skull.
- Direct changes in the electronic pattern of the brain are monitored when an image associated with the event is displayed to the suspect. (Picture of victim/scene of crime/ weapon(s) used etc.)
- The suspect is asked a series of questions about the event.
- If the suspect knows about the event, e.g. weapon used, person present, etc., incriminating brain waves are detected and displayed as a graph with a blue line indicating information the suspect is supposed to know and a red line the information about the event/crime that only someone present or the perpetrator would know.
- Assessment: If the red and blue lines closely correlate the suspect has critical knowledge of the event/crime.

One of the critics of this technique is Professor Peter Rosenfield of the Northwestern University, Evanston, Illinois (US) who expressed his reservations in *Nature*. He says:

> "that not enough attention has been paid to factors that could distort the outcomes of brain fingerprint profiles. Memories change over time, and it could be discovered that psychopaths have very different responses than others. It will take a substantial amount of research before this is ready."

Despite this objection it is claimed that brain fingerprinting has already had several legal successes, including a trial when the accused was found guilty of murder and given a life sentence. Farwell is said to have shown that the accused's brain showed electronic patterns that were not consistent with someone who had been at the scene of the murder. The evidence was rated as admissible at a post-conviction hearing and played a key role in having the accused released in 2003. Another case, said to be the most controversial yet, challenged supporters of the technique. In a murder trial where the accused was found guilty it had been shown that by using the technique the defendant lacked any knowledge of the key details about the crime scene, including the positions of the bodies of the two victims. The accused was found guilty and sentenced to death. The Brain fingerprinting technique and its results are now being used to prevent the execution being carried out. Although the innovative system has been greeted with some scepticism, it is being used in the USA but with the caution that should be reserved for such a fledgling technique.

V.4. Enhancing the power of the brain

Some 20 years ago the first practical demonstration of Transcranial magnetic stimulation (TMS) was made by Professor Anthony Barker at the University of Sheffield (U.K.) The technique used in neuroscience is a way of non-invasive interference of the human brain. The technique has since then been used as a research tool but now it is receiving much attention because of evidence that it might help to mend a damaged brain in particular, and also because its future applications are promising.

In a recent report in the journal *Neuron*, Professor John Rothwell and his colleagues at the University College London (UK) describe how they have improved TMS so that it can boost and fade specific parts of the brain for more than an hour. We are told that it takes only 40 seconds of magnetic stimulation. The electrical pulses are directed through a copper coil, shaped in a figure eight, which is placed against the human's scalp. This induces small electrical currents inside the brain. It works by

> "sending magnetic pulses into the motor cortex, a region that stretches from ear to ear over the top of the head, scientists found they could map how this brain region controls muscles."

In using the device Professor Rothwell can demonstrate that by stimulating a spot, for example, over the left ear he can make a person's right arm twitch. It is claimed that initial safety tests have shown no long-lasting effects.

V.5. Some current applications

There is some evidence from the Centre for the Mind, University of Sydney (Australia) that TMS can act as 'a creativity-amplifying machine. It is claimed that TMS can enhance, for example, the ability to draw and proof-read. This, the Sydney researchers claim, has been verified. Professor Rothwell's team are now investigating this new interest in TMS. Other scientists are now looking at other medical uses.

It has already been claimed that TMS offers a kinder alternative to other forms of treatment. Amongst these are the following treatments which illustrate its importance to

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medical science and to our understanding of many seriopus conditions:

- in electroconvulsive therapy (the treatment of the last resort for people with severe depression).
- in the treatment of severe epilepsy
- in the treatment of patients suffering such as schizophrenics who may hear voices. These may be quietened by TMS treatments.

There are research groups worldwide who are now becoming interested in applying TMS techniques. Currently, most of the research is involved with medical science. Scientists, for example, at the University College, London claim to be able to produce rapid, consistent and controllable changes in the motor cortex, lasting double the amount of time of conventional TMS. The team now seek to use the technique in a number of innovative ways which include:

- sensitising the brain immediately before physiotherapy, so that stroke patients can be helped to regain the ability to move a paralysed limb
- using it in the case of Parkinson's disease where it is hoped that it could help damp down parts of the brain linked with involuntary movements (the side effects of drugs used to treat the disease)

V.6. Developments in research

It has also been reported that Dr Michael Persinger, Laurentian University (Canada), has used TMS to induce electrical changes in the brain's temporal lobes. These have been linked, it would appear, with religious beliefs.

There is no doubt that further researches will reveal more medical applications and make further inroads into our understanding of the complexity of the brain. The ultimate promise is that TMS will provide the means to enhance the brain power of humans and possibly animals. Boosting the IQ of the masses by bombarding a chosen region of the brain or 'brain-washing' using bursts of magnetic energy will provide humankind with yet another set of challenging problems.

VI. ROBOTIC HANDS

Professor Hubertus Murrenhoff and Marcell Meuser of Aachen (Germany) have described the Aachen-IFAS-Hand which is a robotic hand developed at the Rheinisch-Westfälische Technische Hochschule Aachen (The RWTH Aachen University). They believe the robotic hand is 'full of technology' and with fingertip control. It is accepted that whether as prosthetics or robotic hands, artificial hands are used for a variety of applications. A new, pneumatic robotic hand, they say, is making its reputation because of its special grasping and holding abilities.

We are aware that the human hand has been refined over the course of time and is considered to be a nearly perfect grasping and manipulating tool . . . The developers of the Aachen-IFAS-Hand describe it as one:

> "which, while modelled on the characteristics and structure of the human hand, does not try to imitate its appearance.
>
> While the majority of robotic hands developed throughout the world are driven by electric motors or – a few – by compressed fluids, the Aachen robotic hand is the first to be controlled pneumatically, i.e., using compressed air. A pneumatic drive offers a number of advantages over the electromagnetic principle. For one thing, this type of drive does not have to be made of any special materials. Low-density materials such as aluminium or plastic can thus be used, significantly reducing the hands weight. In addition, it is capable of applying strong forces relative to its size with very sensitive pressure control."

Since it only uses air it is considered to be very environmentally friendly in its drive principle. It has the advantage, we are told, that pneumatic drives are very easy to make and are both fire and explosion proof. The pneumatic energy is also very easy to store in containers in the form of compressed air that is generally available. The pneumatic drives are also easy to connect. Pneumatic drives do, of course, have their disadvantages too, *viz* noise, difficult to regulate, etc. Evenso, the ongoing miniaturisation of pneumatic drives and sensors that are used has resulted in the Aachen-IFAS-Hand to be reduced to one and a half times the size of a human hand. It was, however, given only four fingers, because it was considered that only three fingers were needed to securely hold an object and a fourth finger for manipulating it.

The newly developed hand has a total of 11 degrees of freedom, which does mean a total of 11 independent movements. Three different types of pneumatic drives were implemented to use the degrees of freedom and allow the fingers to move.

Professor Murrenhoff and his colleague Marcell Meuser describe the action of the Aachen-IFAS hand in a contribution to the Engineering Sciences section of *German Engineering* (1, 9–11, 2004). They outline the movements involved in a typical grasping task as:

> "performed using both control loops. The fingers are first brought to the object using position control. When the pressure applied in the drives exceeds the value specified for the grasping task as a result of the resistance of the surface of the object, the force control loop takes over. The force control, which uses the pressure within the drives, must be very sensitive: too little force will cause the object to slip, while excessive force can damage or destroy the object."

They indicate that a total of 22 pressure sensors and 11 angle sensors that are integrated within the hand supply the two control loops with the information they require (the pressure levels in the drives and the joint angles). Two pressure sensors are required for each degree of freedom because each drive has two chambers, each of which can be subjected to pressure.

The developers of the new hand say that the signals from these sensors are processed in real-time with measurement and control hardware and converted into position signals for the hand's pneumatic drives.

Currently, in addition to medical uses, artificial hands have found a broad field of application wherever dangerous or life-threatening conditions make it impossible to send human beings. We are reminded that:

> "Situations such as chemical plant accidents or defusing bombs make it desirable to duplicate the natural dexterity of the human hand artificially. Using people for assembly and manufacturing is also becoming ever more complicated. The growing variety

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> of products and rising cost pressures in industry generate a high demand for flexible operating equipment that can simulate the abilities of the human hand more cost effectively."

It is also possible to provide support for people wherever high precision is needed for hours without fatigue. These situations occur in many areas, particularly in the field of medicine where surgeons must perform lengthy operations with great care. The development of robotic hands with sophisticated grasping and holding capabilities is obviously making an enormous contribution to advances in robotics and automation.

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