In the quest for perfection, man is trying his best to develop biological systems with engineering precision, and somewhere in the near future we could have a truly bionic (artificial) man. The good thing is that this could help the disabled and the ailing in a great way.

BIONICS

HELP FOR THE DISABLED

The human body is one of the best creations of nature, for it is an amazing combination of muscles, sensory organs, neural networks et al. But, over a period of time and also due to some unforeseen circumstances, some of these natural combinations cease to work to their potential, or get damaged altogether. So, is it possible to get back the glory bestowed on us by Mother Nature? Is it possible to graft a human organ or restore sensory perceptions to the human body? One major field working towards this is 'bionics', an interdisciplinary approach where different technologies are coming together to make this scenario possible.

According to popular definition, bionics or biomimetics is the application of methods and systems found in nature to the study and design of engineering systems and modern technology. In simple terms, when we think about bionics, it is generally about prosthetic arms or leg enhancements that are worn outside the body and, to some extent, even implanted sensor devices inside the body, which are specifically enhanced to carry out routine tasks. These are essentially life systems that are powered by motors/actuators and sensory arrays. These send neural signals from the affected part of the body to the brain, by which individuals are able to perform some tasks independently.

In a typical scenario, what would happen if you lost a

certain part of your body? Unfortunately, we are not bestowed with such unique regenerating capabilities that the starfish or the common lizard possess to grow back our arms and legs, restoring them to their original state. Stem cell research may be the answer, but no one knows for sure and, till then, it's going to be artificial implants and this is where bionics comes into the picture. Let's take a look at all that could possibly be done to restore or reconstruct a damaged human body.

Developments

The history of bionics begins from ancient mythological times, where soldiers were reported to have replaced their mutilated limbs with artificial ones made of iron ore and gone out to battle. But the present day scenario is influenced by a variety of disciplines, viz. robotics, bioengineering and MEMS, with nanotechnology taking centre stage because it applies detailed precision to engineer body organs and make them function along with human tissues.

The last few decades have been wonderful years for technological advances, both for the medical and the electronics industry in the form of miniaturised electronic components, sophisticated microchips and advanced computer systems—all functionally embedded in the human body. This particular human-to-machine interface, aptly termed as 'Cyborg entities' or 'Bionic bodies', has helped people with physical disabilities (the differently abled) by providing them with artificial limbs, cochlear implants, artificial muscles and other organs to perform tasks, enabling them to lead a notably better lifestyle.

Artificial muscles

What would the human body be without muscles? Just a dangling skeleton! Quite a scary thought! So in the case of damaged muscle, is there a possibility of generating new muscles altogether! Well, yes—one such scenario is the use of EAP or Electroactive Polymers. These are often referred to as artificial muscles and are increasingly being used by researchers to assist humans to overcome deformities. Yoseph Bar-Cohen of NASA's Jet Propulsion Laboratory is the first among equals in the research on EAP. He has conducted several experiments, and has found that these polymers respond exactly like our normal muscles under the influence of electrical stimulation and therefore are the most likely candidates for use in the human body as well as robotic areas of work. Encouraged by the R&D work he had carried out, and confident about the unique properties of EAP, he had issued an open challenge to the world way back in 1999 for an arm wrestling match against a robotic arm made out of EAP. The challenge was finally accepted in March 2005 by a sixteen-year high school student, Panna Felsen, USA, who defeated three robotic arms made out of EAP. Through this experiment, Yoseph Bar-Cohen was able to prove that with further improvement in technology, EAP could one day actually emulate biological muscles and, quite possibly, the verdict might be different the next time around! Now, imagine what a world of difference it would make to people suffering from muscular dystrophy. Again, there's one more interesting capability of EAP—it can be coupled with MEMS to produce smart actuators.

Artificial hearts

So now that we have the muscular body, we need some heartbeat. Our heart is like the engine of the body, pumping blood to various organs and keeping us alive and if that stops…! Artificial development on the heart started around the 1950s when pacemakers were introduced (big mammoths, plugged onto wall units, with which you could move only as far as the extension cord permitted) that allowed people with heart problems some respite. Current pacemakers are tiny. In the technical sense, a pacemaker is a miniaturised electrical generator that

Muscle power enabled by MEMS

Polymers are definitely making progress, as can be seen from the pioneering efforts of Carlos Montemagno, a micro engineer, and his team at the University of California, Los Angeles. The experiment was to use living muscle cells to power Microelectromechanical Systems (MEMS) instead of micro motors, which would act as muscle-based nerve stimulators. Montemagno worked painstakingly for three long years and was finally rewarded.

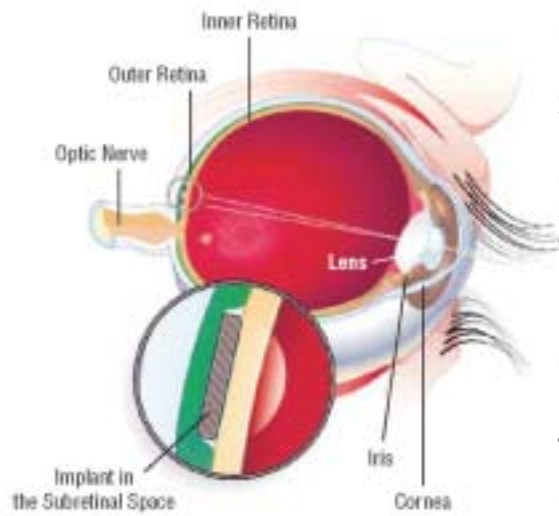
In their lab, the micro engineers used a device—an arch of silicon fifty micrometers wide (half the width of a human hair) on which the team grew a cord of heart muscle fibre (experimenting using rat cells)—all powered by a glucose culture medium on a Petri dish. To achieve the desired conductivity for the structure to grow and move, the team decided to use a gold film that acted as the adherent. Over a period of three days, the entire silicon arch was covered by muscle fibre. Finally, when the restraining beam, which held the musclebot was removed, it started to crawl at speeds of 40 micrometers per second. According to him, the technique when applied to humans would help people with damaged phrenic nerves to breathe easily, and the human muscles would be powered by blood glucose from our own body itself.

consists of a battery that can last a number of years and a computer circuit neatly encased in plastic. This generates tiny electrical pulses to the heart and regulates the rhythm (pacing and sensing) of the heartbeat, while a doctor controls the software for the pacemaker. Any problems and he gets a signal alerting him to rectify it immediately (embedded intelligence). But what about a completely artificial heart?

The Abiocor heart, developed by Abiomed (www.abiomed.com), has been successfully implanted in many patients (though the mortality rate has also been high) and has also helped to prolong life for almost up to six months. The patients who receive artificial hearts are those who are on their deathbeds, with typically not more than 15-20 days of life expectancy. One of the most complicated cases involved Robert Tools, a US-based 58-year old telephone company employee and one-time teacher. He had suffered two early heart attacks, congestive heart failure and was a diabetes patient. Operated on July 2, 2001, to receive the Abiocor heart, he survived for a record 151 days.

Sensory perceptions—bionic eyes and ears

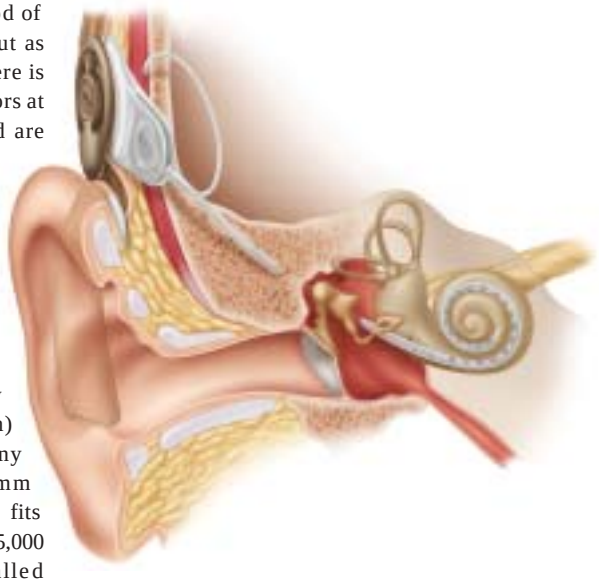
The human eye is made up of millions of rods and cones that enable sight. These have the capability of converting light to electrical impulses, which travel along the optic nerve to the brain where images are formed. But due to diseases such as Retinitis Pigmentosa (RP) and age-related macular degeneration (AMD) the healthy tissues deteriorate, and over a period of time a person can become blind. But as long as the optic nerve is intact, there is still hope. As a result, research doctors at leading institutes around the world are working hard to restore vision to people suffering from such eye diseases. Some of the innovative products developed there are now being surgically implanted for the treatment of vision impairment.



Working on nanoscale dimensions, the artificial silicon retina (ASR) developed by Optobionics (www.optobionics.com) of Naperville, Illinois is a very tiny microchip with a diameter of just 2 mm and thickness of 25 microns. This fits inside the eye and has an amazing 5,000 microscopic solar cells, called microphotodiodes, each with its own individual stimulating electrode. These microphotodiodes act as light sensors that help convert the light energy entering the eye into electrical impulses that stimulate the remaining functional cells of the retina, enabling the person a certain amount of vision. The ASR microchip owes its creation to the Chow brothers—Vincent Chow, an electrical engineer, and Alan Chow, a paediatric ophthalmologist. Using their unique medical and engineering experience, they have been able to create one of the tiniest artificial retinas. Besides these two enterprising brothers there are many who have almost pledged their entire life to the treatment of eye diseases—one notable name being that of Dr William Dobelle (1941-2004), who along with his dedicated team, has been able to restore sight to many blind people around the world. His team has successfully developed a camera-brain interface that relays images to a portable computer and transmits them to electrodes surgically implanted on the brain's visual cortex. The vision represents dot matrix images at first, but over a period of time the person wearing it would be able to see more detailed images.

Cochlear implants

The human ear consists of numerable hair cells that enable hearing, but when these are



damaged, the sound output from the auditory nerves does not reach the brain and a cochlear implant is the only solution for the loss. The implant has a sizeable number of electrodes that replicate the function of hair cells, thereby enabling the hearing frequency and this sound information is passed on to the brain. An interesting development took place recently at the Australian Centre for Medical Bionics and Hearing Science, part of Melbourne's Bionic Ear Institute (www.bionicear.org). Research scientists and other collaborators at the institute are perfecting a bionic ear coated in a smart plastic that would boost the growth of nerve cells in the inner ear when it's zapped with electricity. To get the best sound output for the device, the researchers are using a polymer called polypyrrole, as it has conducting properties. It can even act as biosensors, artificial muscles and be useful to generate solar energy, besides acting as a host structure for molecules to stimulate nerve re-growth.

Professor Gordon Wallace of the Intelligent Polymer Research Institute at the University of Wollongong (www.uow.edu.au) says it serves the dual purpose of regenerating dead nerve cells from the ear as well as treating spinal cord injuries. The device would be powered by a battery, which when zapped with electric current would release the required amounts of the neurotrophin NT3, which regenerates nerve cells.

An e-nose and an e-tongue?

When technology for the eyes and ears has been developed, can the nose and tongue be left behind? The e-nose and e-tongue are very much the subject of discussion in international forums. Joseph R. Stetter and William R. Penrose from the Department of Biological, Chemical and Physical Sciences, Illinois Institute of Technology, are busy working to develop new tastes, detect new odours and finally give the world a sense of taste and smell never imagined before! Sounds interesting! These are typically sensing systems that would have a database of 'n' number of odours and tastes sampled from a variety of resources stored on a tiny microchip that analyses the given taste and smell algorithms.

But who would need it? As a matter of fact, our natural noses and tongues are quite capable of detecting various odours and savouring delicacies. But do we really want to go into that dirty manhole and dig out those samples for scientists to work on and make human kind prosper? This is exactly why robots with such artificial sensing systems are being developed—to be sent on dangerous missions where humans fear to tread.

Human assistance

For most humans, movement is easy but for a quadriplegic it requires supreme effort to even move an inch. What we have seen till now are artificial arms/legs that just pass on as accessories. However, the actual movement of the limbs is possible only when the neural interface stimulates the damaged muscles to do the required action. Thanks to the pioneering efforts of Yoshiyuki Sankai of the University of Tsukuba in Japan, a great enhancement has been possible that would be a boon to people suffering from spinal cord and other injuries. The research scientist has spent over ten years in developing his prototype, HAL (hybrid assistive limb). HAL3, the current version, is a bionic suit equipped with an onboard computer and batteries that power the motor-driven metal "exoskeleton", which has to be strapped on to the legs to assist leg movements.

The bionic suit uses bioelectric sensors attached to the leg muscles and transmits the signals to the onboard computer's database when the person stands, walks, climbs or makes any kind of movement. Besides the above prototype, there are two more in the pipeline—HAL4 and HAL5. The HAL3 weighs a significant 22 kg, while the new prototypes would be far lighter and do away with the backpack as the computer and wireless connections would reside on a small pouch worn on the belt of the bionic suit. The most important development would be that the suits would contain an upper part to assist the arms. This can be used to lift weights up to around 40 kg.

Bionic neurons and the art of stimulation

Thanks to Christopher Reeve, the man fondly remembered the world over as 'Superman' and wheelchair bound Prof Stephen Hawking, the role for research in the field of neurology has been highlighted. After a horse-riding accident that left him paralysed from the neck below, it was almost a miracle that Reeve was able to survive for so many years.

Dr Gerald Loeb, Professor of Biomedical Engineering at the University of Southern California (USC), along with his team, is working on a technology called BIONs, which aims to bring back life into paralysed muscles. These BIONS are wireless electrical devices just around 2 mm wide by 15 mm long, and can be injected into the human body via a hypodermic needle, exactly where they are required. The power source is through radio waves enabled by a small external controller that can be worn by the patient. The most important aspect of these BIONs is that when fully charged, they can deliver good amounts of electrical stimulation to larger muscles with varying intensity.

Currently, they are being tested on people with shoulder dislocations and have been able to restore movements in patients who otherwise had lost hope of those dead muscle cells ever working again. They are biocompatible and pose no threat to the human body even if they are left behind after the treatment is over.

One such bionic device under experimentation was fitted recently (May 2005) at the University of Southampton, using radio frequency microstimulator (AMF—RF microstimulator) devices developed in partnership with the Alfred Mann Foundation (AMF) (http://ami.usc.edu), a not-for-profit medical research organisation based in the US. The project members, led by Dr Jane Burridge, are hopeful of the entire FES trial as the technique allows specific individual muscles to be addressed and their progress can be monitored easily.

The recipient of this treatment was a 46 year-old hairdresser and a keen netball player who had suffered from a stroke nine years ago and again in 2002, which had affected the left side of her body. The device, around 1.7 centimetres long and 2.4 millimetres in diameter, was implanted onto her arm through a small incision that would provide the necessary electrical stimulation to her weak paralysed muscles and help her regain her earlier mobility.

Brain machine interface

The human brain is one complex working mechanism. All our thoughts and actions are controlled by it and research to unravel the subconscious domain is being carried out. To unravel the mysteries of

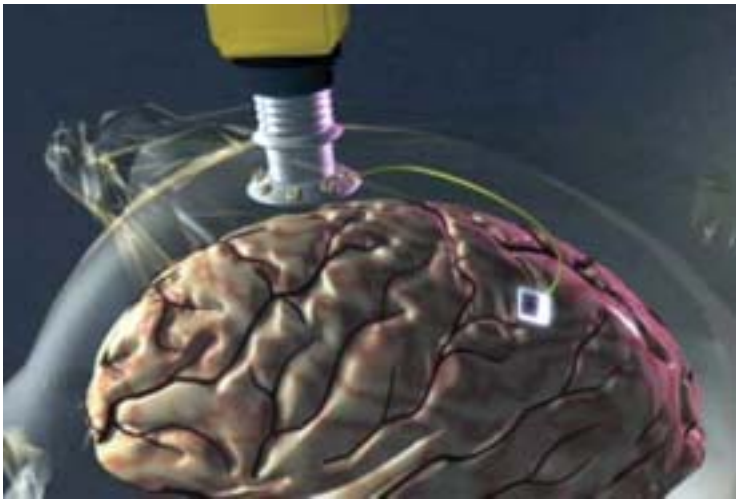
Functional electrical stimulation (FES)

After a paralytic attack or stroke, the individual usually loses some amount of activity on the affected part of the body. Doctors make use of FES to help regain the activity of the motor cells, whereby a low level electrical current is applied to activate the paralysed muscles in a controlled manner.

Biocompatibility

Materials and devices now co-exist in the human body, viz. knee and hip joint replacements, cardiac and dental implants and a host of others. These biomaterials have to be compatible or else they might interfere with the normal functioning of the immune system.

the mind, people have implanted themselves with microchips just to feel how they could benefit from technology. One such person is Prof Kevin Warwick, a true Cyborg in the making. Over the years he has carried out experiments successfully and is keen to try out many more. In Prof Kevin Warwick, we have a healthy person who has got the maximum benefit from technology, but for a disabled person it's a whole new world of experience.

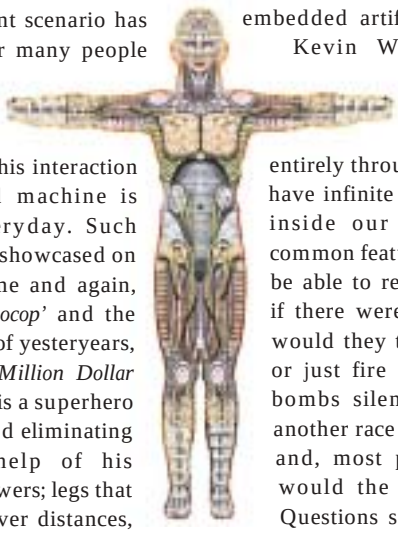


Though some body organs of a disabled person fail to function as required, the brain is still intact, and this is driving research scientists to make use of neural signals and design interfaces to help them in their quest to lead a productive life. BrainGate is one such technology still in the clinical trial stages, developed by Cyberkinetics (www.cyberkinteicsinc.com). Their neural interface system consists of a tiny chip embedded inside the brain of the patient, which processes the thought commands on to a computer screen by which the patient would be able to move the cursor on screen, send e-mails, and play simple games—all just by thinking.

Scientists at Duke University, under the guidance of Miguel Nicolelis, M.D., carried out an experiment funded by DARPA (Defense Advanced Research Projects Agency) where electrodes were connected to the brains of monkeys, and using their brain waves the monkeys operated a robotic arm. The team of neurobiologists who carried out the experiment point out that this research can now be better focused to study brain signals to aid humans suffering from spinal cord and other injuries. DARPA hopes that one day fighter pilots might be able to operate certain controls just by thinking! Wonder what the Wright brothers would have thought of such a novel idea!

Cyborgs

Bionics in the current scenario has made it possible for many people to have several implants in their bodies powered by electronic motors. This interaction between man and machine is getting closer everyday. Such scenarios have been showcased on the silver screen time and again, in '*Terminator*', '*Robocop*' and the most cited example of yesteryears, the TV serial '*The Million Dollar Man*'. The character is a superhero chasing bad guys and eliminating them with the help of his newfound bionic powers; legs that help him to jump over distances, arms strong enough to lift a bulldozer and vision far better than the human eye!



It's quite likely that in the coming years there will be many interesting developments. Let's visualise a scenario somewhere in the future—the year 2080 for example. You go to the doctor for kidney treatment and instead of operating on the defective organ, the doctor suggests you replace your kidney, as fresh body organs are in stock. And it takes hardly a few minutes to get operated on. Those might be the days where a complete kit, which includes heart, lungs and other accessories for the body, could ensure that a completely new person comes out of the hospital. Sounds too far-fetched? But with the rapid progress of technology, who knows!?

We are just getting closer to the above reality as machines are getting smarter and more powerful, thanks to embedded artificial intelligence. Prof Kevin Warwick, the human Cyborg, envisions a future where we would communicate entirely through our thoughts alone, have infinite memory, and biochips inside our bodies would be a common feature. So, would someone be able to read our thoughts? And if there were maniacs amongst us, would they try to control everyone or just fire missiles and detonate bombs silently? Would we have another race more powerful than us and, most pertinent of all, what would the term 'human' mean? Questions such as these are being debated time and again by technology and society experts, but we need to move forward and look at the positive aspect of how technology could be put to better use for mankind—bionics could truly improve the quality of human life.

The Bionic Car—BOX FISH

Mercedes Benz is the automobile maker that needs no introduction. Its three-pointed star emblem is the hallmark of quality, and every car owner would like to possess a Merc. Setting standards is the name of the game for the German giant and what better place to look for inspiration, than nature itself. The Mercedes-Benz Technology Center (MTC) is developing the Mercedes-Benz bionic car—a concept vehicle based on examples inspired from nature. It is aerodynamic, light, saves fuel and is highly advanced…just check it out at http://www.daimlerchrysler.com.

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