# Living Technologies

## Emerging Technologies Based on Biological Systems

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**The animal kingdom provides cues for many technological innovations. Some of the very recent, animal-motivated, technological pursuits are discussed in this article.**

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I was in fact tempted to give the title for this article as 'Bio-technologies', but on second thought I had to restrain myself because of the fact that biotechnology is now generally perceived as synonymous with genetic manipulations. What I want to discuss are those technologies inherent in biological systems, which are emulated or harnessed for human use by various methods including genetic engineering. The structures and functions in the animal kingdom have indeed been inspiring great discoveries. One simple example is the development of airplanes emulating flight of birds. Discussing all such discoveries is not the objective of this article. There are a few, emerging applications based on diverse biological systems, which have been in the news recently. Five such applications are briefly discussed in the following sections.

### 1. Spider Silk Technology

Spider webs have been fascinating scientists, not only because of their intricate designs but also the magical material used to spin them (*Box* 1). Strands of spider silk are a mere one-tenth the thickness of human hair, yet they are strong enough to catch a bee traveling at 32 kilometres per hour without breaking. The strength of a material is expressed in a unit called dernier (1 dernier = 1 gram per 9000 m). The strength of a spider thread is between 5-8 dernier. Compare this with steel, the strength of which is only approximately 3 dernier! Elasticity is an added quality of this thread. The thread of the orb web spider *Araneus diadematus* can be stretched 30 - 40% before it breaks. Steel can be

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**Box 1. Spiders and Webs**

There are about 37000 known species of spiders all over the world. They are one of the most feared groups of invertebrates because of their venom and hairy body. But actually only about 30 species are known to be dangerous to man. They are also fascinating because of their ability to weave webs. The webs are made of special silk produced by several glands located at the spider's abdomen, which produce the silken thread. Every gland produces a thread for a special purpose. The glands known as Glandula Ampulleceae major and minor are used to produce the silk of the walking thread. Glandula Pyriformes is used for the production of the attaching threads. Glandula Aciniformes produces threads for the encapsulation of prey. Glandula Tubiliformes produces thread for cocoons and Glandula Coronatae is used for the production of the adhesive threads. Normally a spider has three pairs of spinners. But there are spiders with only one pair and some others with four pairs of glands. Every spinner has its own function. There are small tubes in the spinners, which are connected to the glands. Three simple forms of webs viz., the sheet web, the orb web and the spatial web are widely recognized. The best known of the three is the orb web. There are many steps involved in the creation of a web. First of all a thin adhesive thread is released from the spinner of the spider. While making the thread longer and longer it is carried by wind to a proper spot where it sticks. Then she walks carefully over the thread strengthening it with a second thread. This is repeated until the primary thread is strong enough. After this she hangs a thread in the form of a Y below the primary thread. These are the first three radial of the web. More radials are constructed taking care that the distance between the radial is small enough to cross. Then the adhesive spiral thread is placed and the web is ready to be used. There could be variations in the standard procedures described above.

stretched only 8% and nylon around 20%. Laboratory tests conducted by researchers at University of California, USA revealed that spider silk is also highly resistant to degradation and can be spun in air or under water. These amazing characteristics make the spider web material ideal for manufacturing a range of products from lighter bulletproof vests to safer suspension bridges.

Traditionally, spider web has been in use for different applications in different parts of the world. Polynesian fishermen use the thread of the golden orb web weaver *Nephila* as fishing line. In the New Hebrides, spider web was used to make nets for the transportation of arrow points, tobacco and dried poison for the arrow points. Spider web was in use as hats among some tribes of New Guinea. During the first world war, the threads of spiders like *Araneus diadematus, Zilla atrica, Argiope aurantia* were used as cross-hair in instruments. In 1709 a Frenchman, Bon de Saint-

Hilaire, demonstrated the possibility of making fabric from spider silk. For this purpose cocoons were boiled, washed and dried and the thread was collected with fine combs. He even produced some socks and gloves with these threads. But a study on the economics of this method revealed that this would never be profitable. It was calculated that 1.3 million spider cocoons were needed to produce one kilogram of silk! In Madagascar there were some attempts to extract spider silk from the forest spider *Nephila*. The method employed was to pull out a thread from the spinner of the spider by hand. The exhausted spiders were then released back to the forest. The silk gathered in this way had a beautiful golden colour. This method too proved uneconomical and also attracted the wrath of environmentalists. A major stumbling block in the way to profitable spider silk harvesting is the difficulty in rearing spiders in huge numbers. This is because they are carnivorous animals and eat each other if kept in the same cage. But a couple of years back scientists came up with new technologies to produce spider silk without live spiders.

Spider web is made up of a protein, which polymerizes to a molecule called fibroin outside the silk gland. Proteins in all living organisms are composed of amino acids, the production of which is controlled by genes. In 2002 scientists at Nexia Biotechnologies Inc., Quebec, Canada along with US Army's Soldier Biological Chemical Command Natick, Massachusetts have managed to isolate the genes responsible for the synthesis of this protein and insert them in the cells of goats [1]. According to them, such re-engineered goats could secrete the spider silk protein in their milk. The silk produced from the protein isolated from the milk was remarkably similar to the natural spider silk. As of now this technology is limited to within the four walls of the laboratory. The application of spider silk technology in the manufacturing industry requires more fine-tuning. The amount of silk-building protein that the scientists were able to produce was limited to a few strands. And it is not clear yet how much protein can be harvested in such a manner. Besides, the experimental silk is only 20-40% as strong as natural spider silk. But the research team is confident of an early resolution of the problem. Nexia already has plans to market the material, dubbed BioStell, for use as fine suture material and biodegradable fishing line, latest by 2004. If things work out further in their favour, we can expect bulletproof vests and bridges made of spider silk in the not very distant future!

Researchers at University of California, USA have a different idea of emulating spider technology. What really interests them are the fibrous form of the spider silk, its extremely fine nature (as fine as .02 microns) and the impressive ability of spiders to change the properties of the silk they produce for different tasks. The fibrous form of the spider silk makes it very conformable and flexible. The ultra-fine nature of the fibre adds still more dimensions to this quality. If a very small diameter material is in linear form, there will be lot of surfaces and thus more reaction sites for a chemical to attach to, and to react with. So there will be more interaction from the material for the same amount of mass. Added to these qualities is the ability of certain nanoparticles[1] to change the composites of the fibres for different functions. For example by adding graphite nanoparticles, the scientists were able to create a material with desirable electromagnetic capabilities, including high conductivity, an important property for aircraft. The researchers used a technology called 'electrospinning' to make fibres of spider silk dimensions. Electrospinning is a process capable of producing fibres less than 100 nanometers in diameter which is 1000 times smaller than a human hair. An electric charge is used to spin a liquid polymer from a needle-shaped device onto a ground plate. The ability to add functionality to a composite benefits a host of industries, the aerospace industry in particular. Space applications, satellites and stealth aircraft all require materials with capabilities of high precision, temperature control, stiffness control, stability and radar absorption. It is hoped that a material with such enhanced qualities would become a reality in the near future, thanks to the tiny spinners.

Nanoparticles are particles having diameter less than 100 nanometer and the technology which deals with such particles is called nanotechnology.

## 2. Insect Technology in Astronomy

In January 2002 a team of Australian based scientists demonstrated devices based on the mechanics of insect flight, that might help explore Mars [2]. The US space agency NASA was immensely impressed by the devices and has plans to utilize the technology on a 2007 mission to the red planet to explore the rock structure of the Valles Marineris, the largest canyon of the solar system. The scientists demonstrated navigational and flight control devices based on research on several types of insects. The resulting sensors are so small that they can be placed on 'microflyers' weighing just 73.5 grams. What prompted the scientists to explore the insect world was their amazing capability of fast and precise aerial maneuvers that require stability and collision avoidance.

One of the first devices the scientists have developed is an electronic model of a simple eye or ocelli of insects (*Figure* 1a).

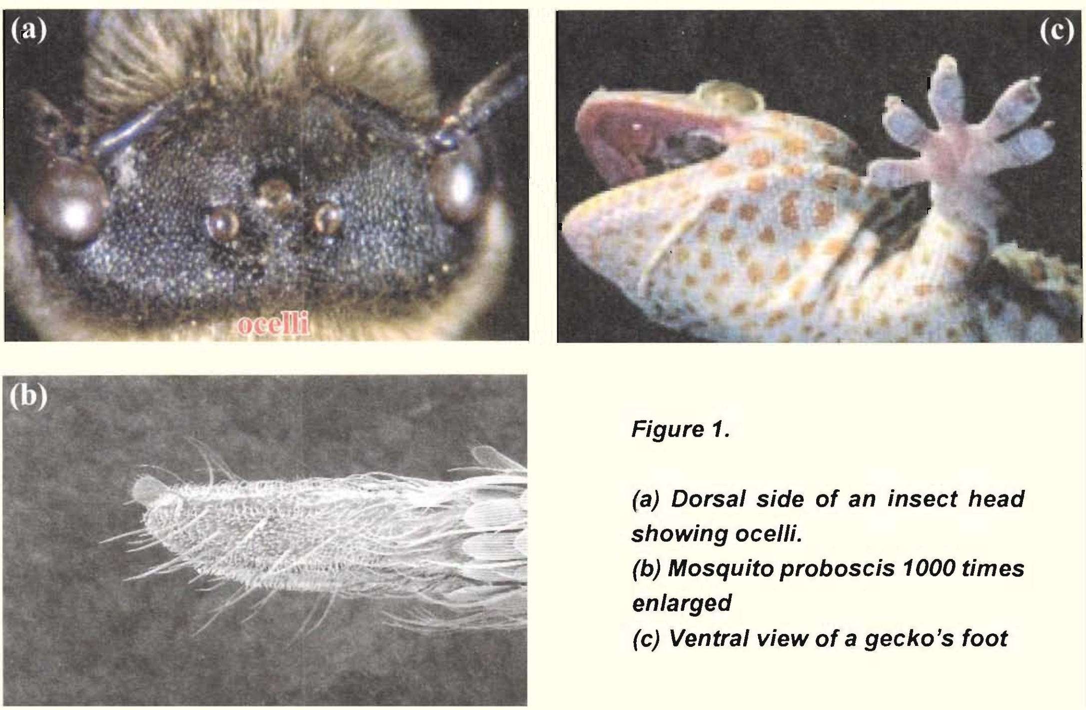


***Figure 1.***

***(a) Dorsal side of an insect head showing ocelli.***
***(b) Mosquito proboscis 1000 times enlarged***
***(c) Ventral view of a gecko's foot***

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The function of ocelli is to measure the distribution of ultraviolet and green light to maintain level flight, which could be an answer to the problem of stable flight in the ultra-thin atmosphere of Mars. According to the scientists the artificial ocelli weigh only a few hundred milligrams, and the collision avoidance sensor around 5 grams. These small sensors would allow small aircrafts, as light as 75 grams, to be carried to the surface of Mars. The scientists also programmed computers to avoid collisions, taking cues from bees, which use the apparent speed of objects to determine distance. Bees may also provide a solution for navigating on Mars, where there is no GPS (Global Positioning System) network or magnetic field to distinguish one pole from another. Bees use a combination of polarization patterns in the sky, landmarks and distance traveled to navigate. The microflyer with its 'insect sensors' is likely to undergo a final test in 2004.

## 3. Painless Syringes Based on Mosquito Proboscis

Here is heartening news for the needle-phobic people all over the world. According to a news item published in *New Scientist*, micro-engineers at Kansai University in Osaka, Japan have developed a prototype of a painless needle [3]. The clue for such a discovery came from an unlikely source: the mosquito proboscis. The mosquito bites by pricking the skin painlessly and the anticoagulant saliva is injected to prevent clotting of blood. The ensuing itching sensation is due to the chemicals in the saliva, not because of the skin injury. The scientists hope that the 'microneedle' developed by them will be the forerunner of small wireless devices for collecting blood that could be permanently attached to the body for monitoring blood-sugar levels in diabetics.

The mosquito bite is painless because the tip of its proboscis is highly serrated and leaves only small points in contact with the skin, reducing the stimulation of nerves. In contrast syringe needles are smooth, and leave a lot of metal in contact with skin tissue. The team created a tiny needle one millimetre long and

0.1 millimetres in diameter with silicon dioxide. The walls of the needle were just 1.6 micrometres thick. This needle was tested on silicone rubber, which mimics the reaction of skin. But there is a big hurdle to overcome before the needle can be tested on humans. The needle they designed is highly brittle and can break while performing a hypodermic injection. This may lead to the formation of a blood clot. If such a clot entered the bloodstream and traveled to the brain or heart it could be fatal. The solution for this problem could be the use of a tougher material produced by 'spider technology' discussed earlier.

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## 4. DNA in Information Technology

Computer chip manufacturers around the world appear to be engaged in a neck-to-neck competition to bring out smaller and faster microprocessors. At present silicon is the element of choice for making chips. The silicon made chips will ultimately reach a saturation point of size and speed. This reality necessitates an alternate material to produce faster computing speeds. A potential candidate is the genetic material DNA (Deoxyribonucleic Acid). While still in their infancy, DNA computers will be capable of storing billions of times more data than a personal computer. In 1994, Leonard Adleman, a computer scientist at the University of Southern California introduced the idea of using DNA to solve complex mathematical problems. This idea struck him after reading the book 'Molecular Biology of the Gene' written by James Watson, who co-discovered the structure of DNA in 1953. In fact, DNA is very similar to a computer hard drive in how it stores permanent information about genes. Adleman's article in a 1994 issue of the journal *Science* outlined how to use DNA to solve a well-known mathematical problem, called the directed Hamilton Path Problem, also known as the 'traveling salesman' problem [4]. The goal of the problem is to find the shortest route between a number of cities, going through each city only once. Adleman chose to find the shortest route between seven cities. The success of the Adleman DNA computer proved that DNA could be used to calculate complex mathematical problems. However, this early DNA computer

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was far from the challenging silicon-based computers in terms of speed. Three years after Adleman's experiment, researchers at the University of Rochester developed logic gates made of DNA. Logic gates, a vital part of the computer, which convert binary code moving through the computer into a series of signals that the computer uses to perform operations. Currently, logic gates interpret input signals from silicon transistors, and convert those signals into an output signal that allows the computer to perform complex functions. The Rochester team's DNA logic gates are the first step toward creating a computer that has a structure similar to that of an electronic computer. Instead of using electrical signals to perform logical operations, these DNA logic gates rely on DNA code. They detect fragments of genetic material as input, splice together these fragments and form a single output. The researchers believe that these logic gates might be combined with DNA microchips to create a breakthrough in DNA computing. It may take many years to develop a workable DNA computer. If such a computer is ever made it is believed to surpass the computing capabilities and compactness of the present day silicon based systems.

## 5. Gecko's Feet for Robots

In 2002, an inter-disciplinary research team working at Lewis & Clark College at Portland, the University of California at Berkeley, the University of California at Santa Barbara, and Stanford University has claimed that they have unraveled the mystery behind the ability of Geckos to climb on smooth surfaces [5]. Their studies confirmed speculation that the gecko's amazing climbing ability depends on weak molecular attractive forces called Van der Waals forces[2] and the adhesive depends on geometry, not surface chemistry. In other words, the size and shape of the tips of gecko's foot hairs determine the stickiness, not the chemical nature as thought earlier. The researchers fabricated prototypes of synthetic foot-hair tips from two different materials for proving their contention. Despite the difference in the materials, the adhesive properties were the same for both the prototypes.

[2] Van der Waals forces, named after a Dutch physicist of the late 1800s, are weak electrodynamic forces that operate over very small distances but bond to nearly any material.

Geckos have millions of microscopic hairs called setae on the bottom of their feet. These tiny setae are only 100 millionth of a meter long, which is approximately double the diameter of human hair. Each seta ends with 1,000 tinier pads at the tip. These tips, called spatulae, are only 200 billionths of a meter wide, below the wavelength of visible light! When billions of such spatulae on the undersurface of gecko feet come into close contact with the surface, molecules in both the spatulae and the surface are attracted to each other. According to one estimate this attraction is so strong that a gecko can hang upside down carrying a weight of 125 kilograms on its back! The researchers are hopeful of manufacturing the first biologically inspired dry adhesive microstructures based on their findings. The advantage of such dry adhesives is their ability to be used on all types of surfaces and also under varied environmental conditions like water and vacuum. Micro-robots with gecko feet can be one of the applications of this technology.

The biological systems will continue to serve as models for many such applications in the coming days. Perhaps the emulation of human brain would be the most thrilling climax for these kinds of technological pursuits.

## Suggested Reading


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