Biomimetics - using nature as an inspiring model for innovation

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ABSTRACT

Evolution has resolved many of nature's challenges leading to lasting solutions with maximal performance using minimal resources. Nature's inventions have always inspired human achievement and have led to effective algorithms, methods, materials, processes, structures, tools, mechanisms, and systems. This field, which is known as Biomimetics, offers enormous potential for inspiring new technologies that can greatly enhance the capabilities of NDE methods. There are numerous examples of biomimetic successes including making simple copies, as the use of fins for swimming. Others examples involved greater complexity of mimicking including the mastery of flying that became possible only after the principles of aerodynamics were better understood. Some commercial implementations of biomimetics, including robotic toys, are increasingly appearing and behaving like living creatures. More substantial benefits of biomimetics include the development of prosthetics that closely mimic real limbs and sensory-enhancing microchips that are interfaced with the brain to assist in hearing, seeing, and controlling instruments. In this presentation, various aspects of the field of biomimetics will be reviewed, examples of inspiring biological models and practical applications will be described, and challenges and potential directions of the field will be discussed.

INTRODUCTION

Nature is the largest laboratory that ever existed and ever will and in its evolution it tested every field of science and engineering leading to inventions that work well and last. Over billions of years, Nature has "experimented" with various solutions to its challenges and has improved the successful solutions. Thus, through evolution nature, or biology, has experimented with the principles of physics, chemistry, mechanical engineering, materials science, mobility, control, sensors, and many other fields that we recognize as science and engineering. The process has also involved scaling from nano and macro, as in the case of bacteria and virus, to the macro and mega, including our life scale and the dinosaurs, respectively. Living systems archive the evolved and accumulated information by coding it into the species' genes and passing the information from generation to generation through self-replication.

Nature has always served as a model for mimicking and inspiration to humans in their desire to improve their life [Bar-Cohen, 2005]. By adapting mechanisms and capabilities from nature, scientific approaches have helped humans understand the related phenomena and the associated principles in order to engineer novel devices and improve their capability. The subject of copying, imitating, and learning from biology was coined *Biomimetics* by Schmitt in [1969]. This field is increasingly involved with emerging subjects of science and engineering and it represents the studies and imitation of nature's methods, designs and processes.

Biomimetics can offer new concepts for NDE and ideas have implemented in such areas as robotics where walking such as crawlers have been used for scanning structures in the field [Bar-

Cohen, 2000]. Examples of capabilities of Nature that NDE technology lagging far behind include the transducers that are used in ultrasonics compared to the capability of the ear. Hearing involves far broader dB sensitivity range, able to sense both the phase and amplitude analysis with ability to detect sound levels that are way below the background noise.

The use of biomimetics is effective not only in developing useful technology related applications such as devices, mechanisms, and algorithms. Non-engineering fields such as art, and architecture are some of the areas that have been using biologically inspired ideas. Other examples include the used of biologically inspired terms for user friendly description of concepts, designs and mechanisms. For example it is very clear which is a *male* or *female* connector, and also what does it means *teeth* of a saw. Other terms derived from biology with their usage clearly understood includes the *heart* to suggest the center, the *head* as the beginning, and the *brain* to describe a computing system. The use of the terms *intelligent* or *smart* suggests the emulation of biological capabilities with a certain degree of feedback and decision making. In the world of computers and software many biological terms are commonly used to describe aspects of technology including *virus*, *worm*, *infection*, *quarantine*, *replicate*, and *hibernate* to name just a few.

STRUCTURES AND TOOLS

Biological creatures can build amazing shapes and structures using materials in their surroundings or materials that they produce and within a give species the details are very close copies. They are also quite robust and support the structure's required function over the duration that they are needed. Such structures include the bees' honeycomb and the birds' nest. Often the size of a structure can be significantly larger than the species that built it, as is the case with the spider's web. Other interesting structures include underground tunnels that gophers build. Birds make their nest from twigs and other materials that are secured to various stable objects, such as trees, and their nests are durable throughout the nesting season. Many nests are hemispherical in the area where the eggs are laid and they offer enough space for the bird to lay on the eggs and have the chicks grow in it until they leave the nest. Even plants offer engineering inspiration, where mimicking the concept of seeds that adhere to an animal's fur, Velcro was invented and has led to an enormous impact in many fields, including clothing and electric-wires strapping.

Because of their intuitive characteristics, the use of biologically-based rules allows for the making of devices and instruments that are user friendly where humans can figure out how to operate using minimal instructions. While honeybees use their honeycomb for its efficient packing structure (which is different than the use for low weight high strength in aerospace), the honeycomb has the same overall shape in both the biological and the aerospace structures. One may argue that the honeycomb structures, which are used in many of the aircraft structures of today's airplanes, were not copied from the bees [Gordon, 1976]. However, since it is a commonly known structure which was invented by nature many years before humans arrived, no patent can be granted in the "patent court" of nature to the first human who produced this configuration.

MATERIALS AND PROCESSES

The body is a chemical laboratory that processes chemicals acquired from nature and turns them to energy, construction materials, waste and various multifunctional structures [Nemat-Nasser et al. 2005; and Mann, 1995]. Natural materials have been well recognized by humans as sources of food, clothing, comfort, and many others where, to name few, one can include fur, leather, honey, wax, milk and silk [Carlson et al. 2005]. Even though some of the creatures and insects that produce materials are relatively small, they can produce quantities of materials that are sufficient to meet human consumption on a scale of mass production (e.g., honey, silk and wool). The use of natural materials can be traced back thousands of years. Silk, which is produced to protect the cocoon of the silkmoth, has great properties that include beauty, strength and durability. The advantages of nature's materials are well recognized by humans and the need to make them in any desired quantity led to the production of artificial versions and imitations.

Some of the fascinating capabilities of natural materials include self-healing, self replication, reconfigurability, chemical balance, and multifunctionality. Many man-made materials are processed by heating and pressurizing, and this is in contrast to nature which always uses ambient conditions. Materials, such as bone, collagen or silk are made inside the organism's body without the harsh treatment that is used to make our materials. The fabrication of biologically derived materials produces minimum waste and no pollution, where the result is biodegradable and is recycled by nature. Learning how to process such materials can make our material choices greater and improve our ability to create recyclable materials that can better protect the environment. Benefits from making effective artificial materials include the development of improved prosthetics, which include hips, teeth, structural support of bones and others.

ROBOTICS EMULATING BIOLOGY

The introduction of the wheel has been one of the most important human inventions - allowing humans to traverse great distances and perform tasks that would have been otherwise impossible within the life time of a single human being [Bar-Cohen and Breazeal, 2003]. While wheel-locomotion mechanisms allows reaching great distances and speeds, wheeled vehicles are subjected to great limitations with regards to traversing complex terrain that have obstacles. Developing a scanner for an aircraft structure using a wheeled robot is significantly harder that the use of a mechanism with legged mobility. Obviously, legged creatures can perform numerous functions that are far beyond the capability of an automobile. Producing legged-robots is increasingly becoming an objective for robotic developers and considerations of using such robots for space applications are currently underway. Also, operating robots as colonies or flocks is a growing area of robotic research.

The field of NDE is increasingly benefiting from the advancement in robotics and automation [Bar-Cohen, 2000]. Crawlers and various manipulation devices are commonly being used to perform variety of inspection tasks from C-scan to contour following and other complex functions. At the Jet Propulsion Laboratory (part of National Aeronautics Space Agency, NASA), a multifunctional automated crawling system (MACS) was developed to simplify the scanners that are used in the field establishing a mobility platform onto which various types of board level NDE instruments can be integrated (see Figure 1). This crawler uses two legs to "walk" on structures while adhering to wall surfaces similar to gecko. While this and other advancements were made to improve the speed and reliability of the inspection, having an on-site human operator is critically needed to assure the reliable operation of these robots. Making a robot that autonomously performs NDE tasks in biologically-like characteristics is still a challenge but with the current trend such a possibility may not be a too distant reality.

FIGURE 1: MACS is shown crawling on the C-5 aircraft [Bar -Cohen, 2000].

Artificial Muscles

Polymers that can be stimulated to change shape and size have been known for years. The functional similarity of such polymers led to their being named artificial muscles. The activation mechanism for such active polymers include electric, chemical, pneumatic, optical, and magnetic. The convenience and the practicality of electrical stimulation, as well as the improved capabilities, make the electroactive polymers (EAP) one of the most attractive among the active polymers [Bar-Cohen 2003, and 2004]. Unfortunately, EAP-based actuators, are still exhibiting low force, are not robust, and are not available as commercial materials for practical application considerations. In 1999, the author challenged the world's research and engineering community to develop a robotic arm that is actuated by artificial muscles to win a wrestling match against a human opponent. The match's objectives are to promote advances towards making EAP actuators that are superior to the performance of human muscles. Also, it is sought to increase the worldwide visibility and recognition of EAP materials; attract interest among potential sponsors and users; and lead to general public awareness since it is hoped that they will be the end users and beneficiaries in many areas including medical, commercial, and military. The first arm-wrestling competition with human was held against a 17-year girl on March 7, 2005 and the girl won against three robotic arms that participated (see Figure 2). Even though the arms did not beat the challenge, one of the arms was able to hold against the girl for 26-seconds and this is an important milestone. From 2006, the competition will be made among EAP actuated robotic arms rather than wrestling with a human. Once advances in developing such arms reach sufficiently high level, a professional wrestler will be invited for the next human vs. machine wrestling match [Further information about this challenge and the related events can be found at: http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/EAParmwrestling.htm]

FIGURE 2: The first armwrestling competition human/EAP robot arm

CONCLUSIONS

After billions of years of evolution, nature developed inventions that work, which are appropriate for the intended tasks and that last. The evolution of nature led to the introduction of highly effective and power efficient biological mechanisms. Failed solutions often led to the extinction of the specific species that became a fossil. In its evolution, nature archived its solutions in genes of creatures that make up the terrestrial life around us. Imitating nature's mechanisms offers enormous potentials for the improvement of our life and the tools we use. Humans have always made efforts to imitate nature and we are increasingly reaching levels of advancement where it becomes significantly easier to mimic biological methods, processes and systems. Advances in science and technology are leading to knowledge and capabilities that are multiplying every year. These improvements led to capabilities to better understand and implement nature's principles in more complex ways. Effectively, we have now significantly better appreciation of nature's capabilities allowing us to employ, extract, copy and adapt its inventions. The inspiration of nature is expected to continue leading to technology improvements and the impact is expected to be felt in every aspect of our lives. Some of the solutions may be considered science-fiction in today's capability, but as we improve our understanding of nature and develop better capabilities this may become an engineering reality that is closer than we think.

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