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Biomimetic Intelligent Creatures and Artificial Muscles

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Abstract- **Biomimetics is an interdisciplinary scientific research focuses on making nature as a model of creative inspiration to study, analyze and design of new efficient engineering systems and modern technology. Smart materials are the foundation supporting the development of new biomimetic based technology. Wide range of biologically inspired robots and intelligent systems has been developed. However, engineering such biomimetic intelligent creatures were hampered by physical and technological constraints, and it is still a challenge. Making robots and intelligent creatures that are actuated by biologically inspired artificial muscles would create new reality with great potentials. This paper provides the concept of Biomimetic as an interdisciplinary field, discusses the enabling technologies, and presents the development of biologically inspired actuators.**

I. INTRODUCTION

The evolution of nature led to the introduction of highly effective and power efficient biological mechanisms. Nature tested every field of science and engineering leading to inventions that work well, can adapt and last. Biological systems exhibit remarkable physical properties and have been always a source of inspiration. Adopting mechanisms and capabilities from nature and the use of scientific approaches led to effective materials, structures, tools, mechanisms, processes, algorithms, methods, systems and many other benefits. Nature has always served as a model for mimicking and inspiration to humans in their efforts to improve their life. Humans throughout history have always sought to mimic the appearance, mobility, functionality, intelligent operation, and thinking process of biological creatures [1].

Maturing conventional technologies are associated with constraints and inadequate performance and this foster the demand for new solutions to maximize functionality while minimizing costs in energy and materials. The need to seek for new solutions is driving science to consider nature as biologically inspired model. The driving force behind attempting to merge biological principles and physics applications stems from the recognition that, there are a number of areas where biological methods are more efficient, environmentally and ecologically friendly, and overall superior to current technology. Hence, understanding biological systems presents unique opportunities for wide range development of innovative ideas, paradigms, concepts and methods for engineering solutions, and helps to create new generations of smart materials, novel advanced structures, intelligent devices and technologies. Engineers are increasingly turning to biologists to understand and learn how living organisms function and solve problems. This leads to fuse the best solutions from nature with artificially engineered components to develop systems that are better in functions and efficiency than existing conventional approaches, and this science and technology became known as "Biomimetics" or the 'Mimicry of Nature'. Researchers diverge in precisely how they define biomimetics [2]. However, the use of inspiration instead of mimics is a more accurate description since mimicry is neither possible nor desirable.

From the view point of the author, Biomimetics can be defined as a new interdisciplinary scientific field featured by technology outcome (hardware and software), and it lies at the interface between biology, physics, chemistry, information, and engineering sciences [7]. Biomimetics focuses on making nature as a model of inspiration that would immensely help conscious abstraction of new principles and ideas, foster innovative design collections, find out new techniques and functionalities, seek new paradigms and methods, develop new materials, and design new streams of intelligent machines, robots, systems, devices, algorithms, etc. Biomimetics incorporates building novel materials at nature's scale and techniques drawn from naturally made substances, and resembles biological systems in structure and/or function as necessary. In the field of sensing and actuations, biomimetics devices can provide an efficient way of converting mechanical energy into electrical or chemical forms and vice versa. Scientists hope this blending may one day lead to stronger, cost- and energy-efficient, and intelligent products that are attractive ecologically.

Today, researchers are looking for any insights they can find into how other biological species do things that the current class of robots cannot with aim at developing a new class of biologically inspired robots that exhibit greater robustness and better performance in unstructured and dynamic environments. This new generation of robots will be substantially more compliant and stable than current robots, and will take advantage of new developments in materials, fabrication technologies, sensors and actuators. Technologies that enable the development of biologically inspired systems are increasingly emerging, such as MEMS and NEMS, artificial muscles, AI and computational intelligence, computer vision, etc. as well as biomimetic capabilities in materials science, mechanics, electronics, computing science, information technology, etc. Making creatures that look and behave like a biological model, such as robots and toys that are greatly inspired by science fiction, have established perceptions and expectations that are far beyond the reach of current engineering capabilities, which are constrained by laws of physics and current state-of-the-art. However, innovative robot design should not be restricted by an animal model's design rather to fuse the best solutions from nature with artificially engineered components.

Researchers in the field of robotics can apply the available research outcomes and lessons that already learnt from biology to practice. How birds fly, how fish swim, how dolphins locate objects, and how humans and other species walk, etc. might best be discovered and understood by trying to understand and abstract the key knowledge from relevant bio-systems. Some of the developed robot design inspired by the biological shape and motion mechanisms selected from the bio-systems family. Such robots may perform combinations of locomotion techniques including legged (two legs [3] four legs [4, 5], six legs [5,6], eight legs [8], etc.), hopping [4, 9], walking and jumping [11], running [4], climbing [12], walking and climbing [13], rolling [14], snake like[16], crawling [17], swimming (underwater, shallow water) [18, 20], water striding [22], flying [23-25], etc. Other development was inspired by behaviors of bio-systems, such as, sensing, navigation, formation, tracking, etc. [27, 29, 30].

In spite of such development, current robots lack the robustness and performance of even the simplest insect or animal when operating in dynamic, unstructured and complex environments. Even if the design of biomimetic robots is inspired from biology, however, their realizations were in most cases compromised by the complexity and fragility that result due to the use of traditional engineering materials and manufacturing methods [6]. It should be kept in mind that mimicking animals, or even plants, requires deep investigation of new materials, mechanisms, sensors, actuators, and control schemes and can lead to breakthrough advances of robotics technologies.

II. BIOMIMETICS AND ENABLING TECHNOLOGIES

The growing effect of interdisciplinary technology is changing the world across all dimension of life: social, health, education, manufacturing, industry, economic, political, personal, etc. The revolution of information technology, information availability and utilities continue to influence the world in all life dimensions. Biotechnology is revolutionizing our life by enabling us to identify, understand, manipulate, improve, and control every aspect of living organisms. Smart materials, agile manufacturing, and nanotechnology are inspiring, enabling, and offering the promise of a new dimension in innovation of new devices with unforeseen capabilities that we have not seen. Biotechnology relies heavily on laboratory equipment providing lab-on-a-chip analysis as well as progress in bioinformatics. Many of the advances in lowering energy intensity have come from developments in the materials and chemical sciences, such as new magnetic materials; high strength, lightweight alloys and composites; novel electronic materials; and new catalysts, with a host of energy technology applications. Materials sciences are helping in the development of energy generation, conversion, transmission, and use, while chemical sciences provide the necessary understanding of the interactions of atoms, molecules, and ions with photons and electrons; the making and breaking of chemical bonds in gas phase, in solutions, at interfaces, and on surfaces; and the energy transfer processes within and between molecules.

Our bodies can be viewed as complex assembles of molecular-level machines [21]. Biolmolecular motors are individual protein complexes that are ultimately responsible for all active biological motion involving internal material transport. They perform tasks vital to life of the organism, such as muscle contraction, damage repair, cell division, intracellular transport and genomic transcription [10]. The success of future molecule-driven actuators most likely lies in the development of artificial molecular motors because of their ability to provide large forces from low voltage inputs while featuring bistable actuation characteristics and molecular design flexibility. In order to develop mechanical parts in the nanometer range, and thereby create nano-electromechanical systems (NEMS) [26] that may be used beyond those satisfied by current MEMS devices, different fabrication methods have been initiated [10, 19, 28]. Biomimetic synthetics are being used to encourage bone regeneration and interaction with human implants and orthopaedic implants. The smaller the particle size of the material used, the better the result as far as tissue growth and regeneration. Recent developments are using nanotechnology to produce molecular level changes to materials in order to mimic natural found materials

Nano- and smart materials technologies are changing the way structures and electronics are made, and promise the development of useful components, products and systems for desired characteristics that are highly stronger, smaller (composed of just a few atoms and molecules), smarter, high resolution, lighter weight, faster, accurate, reliable, structural functionality and flexible, and self-repairing, multi-functional, user and environment friendly, efficient energy conversion and storage, more survivable, customizable, etc. The revolution in genomics research has the potential to provide entirely new ways of producing forms of energy, sequestering carbon, and generating materials that require less energy to produce. It includes research to investigate the underlying biological processes of plants and microorganisms, potentially leading to new processes and products for energy applications.

Different materials with sensing and actuation capabilities are increasingly used to combine these capabilities in response to various needs, such as, new smart and specialized equipment and systems; monitoring and diagnosis for health, industry, structures and environment; security and tracking; realizing new clothes that can respond to weather and health or comfort, interface with information systems, monitor vital signs, deliver medicines, and protect wounds; personal identification; supporting new trends in building intelligent transportation systems, etc. Rapid prototyping, and flexible manufacturing together with embedded sensors and systems, has provided a means for accelerated and affordable design and development of complex components and systems. Hardware advances for exponentially smaller, faster, and cheaper semiconductors are supporting the growth of information technology. This trend in technology increases the availability of low-cost computing, high memory devices, and enable the development of ubiquitous embedded sensors and computational systems in consumer products, intelligent system, appliances, and environments. The evolution of these technologies is leading to the development of new trend of instrumentation and measurement technologies along with chemical, fluidic, optical, mechanical, and biological integrated micro- and nano-scale components, which are integrated with computational logic in chip designs. Increases in materials performance for power sources, sensing, and actuation could also enable new and more sophisticated classes of robots and remotely guided vehicles based on biological models. A potential long-term solution to overcome possible limitation in computational power is to shift the basis of computation to devices that take advantage of various quantum effects. In addition, another approach known as molecular electronics would use chemically assembled logic switches organized in large numbers to form sophisticated devices and computers. These concepts are attractive because of the huge number of parallel, low-power devices that could be developed.

The biomimetics field is highly interdisciplinary and all of the mentioned technologies that contribute to its progress are highly inter-related and heavily synergized, which makes the progress of each area leads to accelerate progress in each of the other areas. In addition, biomimetics is demanding to increase the importance of continued interdisciplinary education, training and research. The progress of the mentioned fields is highly contributing to improve life quality by having better disease control, new medicines and treatments, gene therapy, age mitigation and reversal, prosthetics, bionic implants, animal transplants, and many other advances. The accelerating pace of the advancements in the field of biomimetics seems to make evident that the emergence of machines as our peers is imminent. Further advancement and the actual realization of these possibilities depends on a number of factors, including local acceptance of technological change, levels of technology and infrastructure investments, market drivers and limitations, and technology breakthroughs and advancements.

III. Bioinpiration and Actuation materials

Along with limitations in current control methodologies, actuation presents constraints to novel designs of intelligent mechanisms. Three types of conventional actuation are considered as the core of motion and force power for all motion based systems: Hydraulic, Pneumatic, and Electromagnetic actuators. However, the challenges of energy inefficiency, flexibility, robustness and other technical motivations have been many in getting robots to perform bio-inspired motion, such as that of human, animal, insect, etc. Hence, there are demands to develop technologies that would drive robots with efficient, high power density actuation and achieve lifelike motion performance. The most significant difficulty in achieving lifelike performance or appearance is the lack of actuator technology that can truly mimic natural muscles even at its most basic performance. Natural muscles are essential to the mobility and manipulation capabilities of biological creatures. This highlights the need and the necessity to develop actuators that emulate and supersede the behavior and performance of real muscles. The potential to make such actuators is increasingly becoming feasible with the emergence of new development. Recently, many new types of actuators and materials have been used or currently under development to provide the necessary motion and force input. Examples of these actuators are Shape Memory Alloys, Electro-Rheological Fluids, Magneto-Active Transducers, single Crystal Piezoelectric ceramics, Carbon nano-tubes, Electrostatic, and Electroactive Polymers.

Electroactive polymers artificial muscles (EPAM), dielectric elastomers (DE), electroelastromers are terms used to indicate to electroactive polymers (EPA) [31]. The basic architecture of EPAM actuator is made up of a dielectric polymer film sandwiched between two compliant electrodes, typically 10 to 200 um thick that is coated on both sides with an expandable and compliant film of a conducting electrode material, such as carbon impregnated elastomer. The potential of this technology is immense as electroactive polymers that perform muscles activities by expanding and contracting silently based on small variable voltage input levels. The good electromechanical response of EPAM, as well as other characteristics such as good environmental tolerance and long-term durability, suggests a wide range of possible applications. The significant advantage EPAM has over electromagnetic actuators is energy density, i.e., more energy created per unit mass of the actuator itself. In addition, EPAM has a significant direct displacement advantage compared to other evolving technologies. The EPAM materials can be easily formed in various shapes and their properties can be engineered and they can potentially be integrated with micro-electro-mechanical-system (MEMS) sensors to produce smart actuators. EPAM has the ability to be configured and tailored to particular applications. These include rolled actuators, actuators based on stretched films on rigid frames, bimorph and unimorph actuators, diaphragms, and bowtie actuators (so called because the top and bottom rigid end pieces, together with the flexible sides that come in at an angle, make the shape of a bowtie) [15]. Furthermore, one can have multi layer of EPAM to get additional displacement or stroke as well as getting higher exerted forces. These layers can be constructed in multiple planar configurations or in linear rolls. The EPAM can be patterned to pinpoint actuation in multiple locations. The overall displacement is a function of the area of EPAM, and the force exerted is a function of the number of layers of EPAM.

Dielectric elastomers have the ability to emulate the operation of biological muscles with high fracture toughness, large actuation strain and inherent vibration damping. Their unique characteristics make them promising materials in electromechanical transduction and active vibration damping Many prototypes have been developed seeking to embody the advantages of the dielectric elastomers and create biologically inspired intelligent robots and machines [31-33]. Nevertheless, the EAP materials that have been developed so far are still exhibiting low conversion efficiency, are not robust, and there is a need for developing adequate understanding of EAP materials' behavior, as well as processing and characterization techniques [33].

IV. CONCLUSIONS

Duplicating nature's designs is not an easy task and it is not always necessary either. A reality check reveals that creative inspiration comes a lot easier than imitation. By studying and analyzing biological systems, one may be able to derive or understand the relevant principles and use them to help solve engineering problems. However, the main challenge facing the development of Biomimetics robots and systems is the available technology, materials and the methods of fabrication as it is still in their infancy compared to nature's evolution. Biomaterials are expected to become the dominant focus of materials research, as it would lead to down-sizing of engineered components and the up-scaling incorporation of biomimetic concepts and processes. The inspiration of nature is expected to continue leading to technology improvements and the impact is expected to be felt in every aspect of human life. Finally, in order to achieve desirable lifelike motion, actuators must be able to reproduce the important features of natural muscle.

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