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Keynote Presentation

Biologically Inspired Intelligent Robots Using Artificial Muscles

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Abstract

Humans throughout history have always sought to mimic the appearance, mobility, functionality, intelligent operation, and thinking process of biological creatures. This field of biologically inspired technology, having the moniker biomimetics, has evolved from making static copies of human and animals in the form of statues to the emergence of robots that operate with realistic appearance and behavior. Technology evolution led to such fields as artificial muscles, artificial intelligence, artificial vision and biomimetic capabilities in materials science, mechanics, electronics, computing science, information technology and many others. One of the newest fields is the artificial muscles, which is the moniker for electroactive polymers (EAP). Efforts are made worldwide to establish a strong infrastructure for this actuation materials ranging from analytical modeling and comprehensive understanding of their response mechanism to effective processing and characterization techniques. The field is still in its emerging state and robust materials are still not readily available however in recent years significant progress has been made. To promote faster advancement in the field, in 1999, the author posed a challenge to the research and engineering community to develop a robotic arm that would wrestle against human opponent and win. Currently, he is considering setting up the first competition in 2005. This paper covers the current state-of-the-art and challenges to making biomimetic robots using artificial muscles

Keywords: EAP, artificial muscles, biomimetics

1. Introduction

Robotics has been an evolution of the field of automation where there was a desire to emulate biologically inspired characteristics of manipulation and mobility. In recent years, significant advances have been made in robotics, artificial intelligence and others fields allowing to make sophisticate biologically inspired robots [Bar-Cohen and Breazeal, 2003]. Using these advances, scientists and engineers are increasingly reverse engineering many animals' performance characteristics. Biologically inspired robotics is a subset of the interdisciplinary field of biomimetics. Technology progress resulted in machines that can recognize facial expressions, understand speech, and perform mobility very similar to living creatures including walking, hopping, and swimming. Further, advances in polymer sciences led to the emergence of artificial muscles using Electroactive Polymer (EAP) materials that show functional characteristics remarkably similar to biological muscles.

Making creatures that behave like the biological model is a standard procedure for the animatronics industry that is quite well graphically animates the appearance and behavior of such creatures. However, engineering such biomimetic intelligent creatures as realistic robots is still a challenge due to the need to physical and technological constraints. Making simple tasks such as hopping and landing safely without risking damage to the mechanism, or making body and facial expression of joy and excitement, which are very easy tasks for human and animals to do, are extremely complex to engineer. The use of artificial intelligence, effective artificial muscles and other biomimetic technologies are expected to contribute to the possibility of making realistically looking and behaving robots. At the current development pace of the advancements in biomimetics it is becoming more realistic to expect the inevitability of the development of machines as our peers.

While the engineering challenges are very interesting to address there are also fundamental issues that need attention. Some of these issues include self-defense, rituals for interactions with human, controlled-termination, definition of standard body language for such robots as well as many others. There is already extensive heritage of making robots and toys that look and operate similar to biological creatures and models for such robots are greatly inspired by science fiction (e.g., books, movies, toys, and animatronics). This heritage has created 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. This paper focuses on the topic of artificial muscles, their state-of-the-art and the challenges to using them to make fully functional biomimetic intelligent robots.

2. Biology and nature as inspiring models

Evolution over millions of years in nature led to the introduction of highly effective and power efficient biological mechanisms. Imitating these mechanisms offers enormous potentials for the improvement of our life and the tools we use. Humans have always made efforts to imitated nature but the improvement in technology it is becoming easier to make such adaptation.

The introduction of the wheel has been one of the most important invention that human made allowing to traverse great distances and perform tasks that would have been otherwise impossible within the life time of a single human being. While wheel locomotion mechanisms allow reaching great distances and speeds, wheeled vehicles are subjected to great limitations with regards to traversing complex terrain with obstacles. 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. Making miniature devices that can fly like a dragonfly; adhere to walls like gecko; adapt the texture, patterns, and shape of the surrounding as the octopus (it can reconfigure its body to pass thru very narrow tubing); process complex 3D images in real time; recycle mobility power for highly efficient operation and locomotion; self-replicate; self-grow using surrounding resources; chemically generate and store energy; and many other capabilities are some of the areas that biology offers as a model for science and engineering inspiration. While many aspects of biology are still beyond our understanding and capability, significant progress has been made. Adapting mechanism of nature may be more effective to make by mimicking the functional capability rather than fully copying the mechanisms. The airplane is one such an example where human made attempts over to fly like birds over many centuries. There is no doubt that human has significantly surpassed biology in flying way higher, faster and perform function that are far beyond any creature capability.

3. Artificial muscles

Muscles are the key to the mobility and manipulation capability of biological creatures and when creating biomimetic it is essential to create actuators that emulate muscles. The potential to make such actuators is increasingly becoming feasible with the emergence of the electroactive polymers (EAP), which are also known as artificial muscles [Bar-Cohen, 2001]. These materials have functional similarities to biological muscles, including resilience, damage tolerance, and large actuation strains. Moreover, these materials can be used to make mechanical devices with no traditional components like gears, and bearings, which are responsible to their high costs, weight and premature failures. The large displacement that can be obtained with EAP using low mass, low power and, in some of these materials also low voltage, makes them attractive actuators. The capability of EAPs to emulate muscles offers robotic capabilities that have been in the realm of science fiction when relying on existing actuators.

FIGURE 1: A graphic illustration of the grand challenge for the development of EAP actuated robotics – an armwrestling match against human.

Unfortunately, the EAP materials that have been developed so far are still exhibiting low conversion efficiency, are not robust, and there are no standard commercial materials available for consideration in practical applications. In order to be able to take these materials from the development phase to application as effective actuators, there is a need for an established infrastructure. For this purpose, it is necessary to develop comprehensive understanding of EAP materials' behavior, as well as effective processing, shaping and characterization techniques. The technology of artificial muscles is still in its emerging stages but the increased resources, the growing number of investigators conducting research related to EAP, and the improved collaboration among developers, users, and sponsors are leading to a rapid progress. In 1999, the author posed a challenge to the worldwide research and engineering community to develop a robotic arm that is actuated by artificial muscles to win an arm wrestling match against a human opponent (Figure 1). Progress towards this goal will lead to significant benefits, particularly in the medical area, including effective prosthetics. Recent progress is enabling to consider holding the first armwrestling competition possibly in March 2005 [http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/armsports.htm].

4. Biomimetic robots using EAP

Mimicking nature would significantly expand the functionality of robots allowing performance of tasks that are currently impossible. As technology evolves, great number of biologically inspired robots actuated by EAP materials emulating biological creatures is expected to emerge. The challenges to making such robots can be seen graphically in Figure 2 where human-like and dog-like robots are shown to hop and express joy. Both tasks are easy for humans and dogs to do but are extremely complex to perform by existing robots.

FIGURE 2: Making a joyfully hopping human-like and dog-like robots actuated by EAP materials are great challenges for biomimetic robots

Acknowledgement: The human-like graphics was created by Robert M. Brown, JPL, where Zensheu Chang, JPL, was photographed hopping and smiling, whereas the eyes and nose of Jill Bonneville, JPL, were superimposed onto the face. The dog graphics is the contribution of David Hanson, U. of Texas, Dallas. This graphics was modified by Robert M. Brown, JPL

To promote the development of effective EAP actuators, which could impact future robotics, toys, and animatronics, two platforms were developed (see Figure 3). These platforms are available at the author's lab in JPL and they include an Android head that can make facial expressions and a robotic hand with movable joints. At present, conventional electric motors are producing the required facial expressions of the Android. Once effective EAP materials are chosen, they will be modeled into the control system in terms of surface shape modifications and control instructions for the creation of the desired facial expressions. Further, the robotic hand is equipped with tendons and sensors for the operation of the various joints mimicking human hand. The index finger of this hand is currently being driven by conventional motors in order to establish a baseline and they would be substituted by EAP when such materials are developed as effective actuators.

FIGURE 3: An android head and a robotic hand that are serving as biomimetic platforms for the development of artificial muscles

Acknowledgement: This photo was made at JPL where the head was sculptured and instrumented by David Hanson, University of Texas, Dallas. And the hand was made by Graham Whiteley, Sheffield Hallam U., UK.

The field of artificial muscles offers many important capabilities for the engineering of robots. The easy capability to produce EAP in various shapes and configurations can be exploited using such methods as stereolithography and ink-jet processing techniques. Potentially, a polymer can be dissolved in a volatile solvent and ejected drop-by-drop onto various substrates. Such rapid prototyping processing methods may lead to mass-produced robots in full 3D details including the actuators allowing rapid prototyping and quick transition from concept to full production [Bar-Cohen, 2001]. While such capabilities are expected to significantly change future robots, additional effort is needed to develop robust and effective polymer-based actuators.

5. Remote presence via haptic interfaces

Remotely operated robots and simulators that involve virtual reality and the ability to "feel" remote or virtual environment are highly attractive and offer unmatched capabilities [Chapter 4 in Bar-Cohen and Breazeal, 2003]. To address this need, the engineering community are developing haptic (tactile and force) feedback systems that are allowing users to immerse themselves in the display medium while being connected thru haptic and tactile interfaces to allow them to perform telepresence and "feel" at the level of their fingers and toes. Recently, the potential of making such a capability with high resolution and small workspace was enabled with the novel MEMICA system (MEchanical MIrroring using Controlled stiffness and Actuators) concept [http://ndeaa.jpl.nasa.gov/nasa-nde/memica/memica.htm]. For this purpose, scientist at JPL and Rutgers University used an EAP liquid, called Electro-Rheological Fluid (ERF), which becomes viscous under electro-activation. Taking advantage of this property, they designed miniature Electrically Controlled Stiffness (ECS) elements and actuators. Using this system, the feeling of the stiffness and forces applied at remote or virtual environments will be reflected to the users via proportional changes in ERF viscosity.

6. Biologically inspired robots

The evolution in capabilities that are inspired by biology has increased to a level where more sophisticated and demanding fields, such as space science, are considering the use of such robots. At JPL, a six-legged robot is currently being developed for consideration in future missions to such planets as Mars. Such robots include the LEMUR (Limbed Excursion Mobile Utility Robot). This type of robot would potentially perform mobility in complex terrains, sample acquisition and analysis, and many other functions that are attributed to legged animals including grasping and object manipulation. This evolution may potentially lead to the use of life-like robots in future NASA missions that involve landing on various planets including Mars. The details of such future missions will be designed as a plot, commonly used in entertainment shows rather than conventional mission plans of a rover moving in a terrain and performing simple autonomous tasks. Equipped with multi-functional tools and multiple cameras, the LEMUR robots are intended to inspect and maintain installations beyond humanity's easy reach in space with the ability to operate in harsh planetary environments that are hazardous to human. This spider looking robot has 6 legs, each of which has interchangeable end-effectors to perform the required mission (see Figure 4). The axis-symmetric layout is a lot like a starfish or octopus, and it has a panning camera system that allows omni-directional movement and manipulation operations.

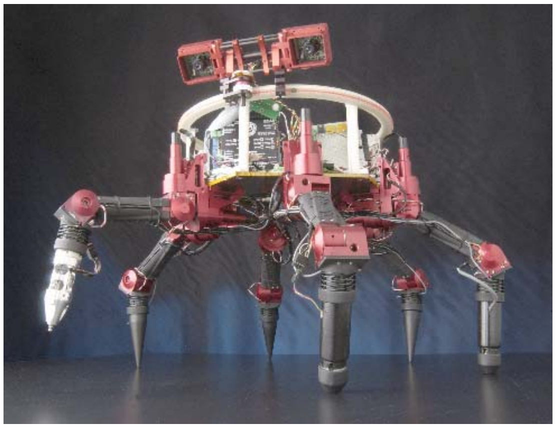

FIGURE 4: A new class of multi-limbed robots called LEMUR (Limbed Excursion Mobile Utility Robot) is under development at JPL [Courtesy of Brett Kennedy, JPL]

7. Robots as part of the human society

As robots are getting the appearance and functionalities of humans and animals there is a growing need to make them interact and communicate as a sociable partner rather than a tool. This trend is requiring that robots would be able to communicate, cooperate, and learn from people in familiar human-oriented terms. Such a capability poses new challenges and motivates new domestic, entertainment, educational, and health related applications for robots that play a part in our daily lives. It requires obeying a wide range of social rules and learned behaviors that guide the interactions with, and attitudes toward, interactive technologies. Such robots are increasingly emerging and one example of such a robot is the Kismet that was developed by Breazeal [2002]. Kismet perceives a variety of natural social cues from visual and auditory channels, and delivers social signals to people through gaze direction, facial expression, body posture, and vocalizations.

8. Concluding remarks

Technologies that allow developing biologically inspired system are increasingly emerging. These include robots can walk, hop, swim, dive, crawl, etc. Making robots that are actuated by artificial muscles and controlled by artificial intelligence would enable engineering reality that used to be considered science fiction. Using effective EAP actuators to mimic nature would immensely expand the functionality of robots that are currently available. Important addition to this capability can be the application of tele-presence combined with virtual reality using haptic interfaces. Further, making such robots capable to understand and express voice and body language would increase the probability of seeing them as social partner that a machine or tool. As the technology advances are made, it is more realistic to expect that biomimetic robots will become commonplace in our future environment. It will be increasingly difficult to distinguish them from organic creatures, unless intentionally designed to be fanciful. As we are inspired by biology to make more intelligent robot to improve our lives we will increasingly be faced with challenges to such implementations. A key to the development of such robots is the use of actuators that mimic muscles, where electroactive polymers (EAP) have emerged with this potential. A series of new artificial muscle materials were developed while the technology infrastructure is being established towards making more efficient material and design effective mechanism. The author's arm-wrestling challenge having a match between EAP-actuated robots and a human opponent highlights the potential of this technology. This match may occur in March 2005 and success of a robot against human opponent will lead to a new era in biomimetic robots.

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