Electroactive Polymer (EAP) actuators for future humanlike robots

Yoseph Bar-Cohen
Jet Propulsion Lab, California Institute of Technology
4800 Oak Grove Drive, Pasadena, CA 91109-8099
yosi@jpl.nasa.gov, web: http://ndeaa.jpl.nasa.gov

ABSTRACT

Human-like robots are increasingly becoming an engineering reality thanks to recent technology advances. These robots, which are inspired greatly by science fiction, were originated from the desire to reproduce the human appearance, functions and intelligence and they may become our household appliance or even companion. The development of such robots is greatly supported by emerging biologically inspired technologies. Potentially, electroactive polymer (EAP) materials are offering actuation capabilities that allow emulating the action of our natural muscles for making such machines perform lifelike. There are many technical issues related to making such robots including the need for EAP materials that can operate as effective actuators. Beside the technology challenges these robots also raise concerns that need to be addressed prior to forming super capable robots. These include the need to prevent accidents, deliberate harm, or their use in crimes. In this paper, the potential EAP actuators and the challenges that these robots may pose will be reviewed.

Keywords: Biomimetics, biologically inspired technologies, robotics, EAP, electroactive polymers

1. INTRODUCTION

Nature produced enormous pool of inventions that resulted for many millions of years of evolution leading to solutions that work well and are durable offering models for mimicking and inspiration [Bar-Cohen, 2005]. Throughout the history of our human civilization the value of Nature's inventions was well recognized and many tools were developed. In recent years, using the powerful technologies and capabilities that are available today, there has been a significant rise in seeking more complex possibilities of mimicking biology and the field is becoming widely known as biomimetics. Making machines that appear as well as perform functions and tasks like humans, i.e., humanlike robots, is the ultimate challenge to inspiration and mimicking of biology. However, if their capability is advanced to the point that turns them to machine that are very smart with self-identity and cognitive behavior they will not be just another tool anymore. These robots have many limitations but their capability is still quite impressive considering the fact that these robots are based only on the first fifty years since intelligent machines started emerging [Bar-Cohen and Hanson, 2009]. As opposed to current robots that are used in industry where they are fixed in place and perform functions related to making and testing commercial products, humanlike robots are intended to be mobile and autonomous raising many concerns that need to be addressed before they cause harm to humans and/or properties. The entry of robots into consumers' homes is still slow where the most widely used robot is only the vacuum cleaner called Roomba (made by iRobot). This robot, with millions of units sold already, has a disk shape and it vacuums the floor while traveling from one end of the house to the other avoiding obstacles and staying within defined bounds. Making robots that are shaped and perform like humans has been going on for decades and recent advances led to humanoid robots that have the general shape of a human, as well as humanlike robots with significant similarity to humans [Bar-Cohen and Hanson, 2009]. Leading manufacturers in Japan are already producing various prototypes and investigating the potential of marketing humanoids and examples include Asimo (made by Honda), HOAP robots (made by Fujitsu), and the Partner Robots (made by Toyota). The commercial humanlike robots are mostly marketed in the form of toys including the Hasbro's Baby Alive doll and the Mattel's Miracle Moves Baby doll, which are able to move and perform functions that make the toy look and act like a real baby.

The humanoid robots, which are already being commercialized for various industrial applications, have helmet-like head and do not have facial features except possibly for cameras that resemble eyes. These robots perform relatively limited functions and they are quite "power-hungry" restricting their operation range and duration of usage since their batteries have a charge that can last an hour or less depending on the model and the robot's performed tasks. The developed robots are mostly being made towards establishing commercial applications for both consumer and industrial markets. Eventually, the market that these robots are expected to generate is estimated to reach billions of dollars. However, they are still far from becoming a household machine. In 2005 Sony, who was a leading developer of such robots, started commercializing its child-size robot QRIO (Quest for curiosity) but on January 26, 2006 it announced the cancellation of any further development of its humanoid robots. In the experimental marketplace of robotics, not every product is a success, and the QRIO can be considered a loser in this natural selection process and the survival of the fittest.

Making robots that have humanlike appearance is quite a challenge and these robots are mostly being developed at academic and research institutes. Some of the issues that are facing the development of these robots include phobia, which is related to what is known as the Uncanny Valley Hypothesis [Bar-Cohen and Hanson, 2009]. Generally, we tend to be excited about seeing robots made with increasing similarity to humans and we are still forgiving with the limitation in appearance and performance. However, the closer these robots will be made to look and behave like humans the more critical we are expected to become towards their deficiencies. Since the functions of the developed robots are still far from the capability of biological creatures, some of the commercial robots are being shaped as humanoids.

There have been many types of humanoids and humanlike robots that were developed in many countries worldwide and they are being considered for various applications including health-care, entertainment, military, homeland defense and many others [Bar-Cohen and Hanson, 2009]. While still limited in number of developed humanlike robots, there has been a great increase in the number of reported new ones from such countries as Japan, Korea and China. Also, researchers and engineers in other counties are also contributing to the development of this technology. In Japan, besides economical factors, the effort to make humanlike robots is motivated by the significant reduction in population resulting from their record low birthrate and from their having the longest lifespan worldwide. With the second-largest economy in the world, employers in Japan are greatly concerned of future inability to fill jobs that require low-level skills and that may be dirty, dangerous, and physically demanding. For elderly, disabled or patients in rehabilitation, these robots may provide twenty-four hours seven days a week monitoring assistance. As the development in this technology becomes more successful it will be increasingly important to distinguish them from organic creatures. Robots that appear as lifelike humans are already being made to operate like receptionists, guards, hospital workers, guides, and more. These robots are made to speak in various languages, dance to the sound of music, play musical instruments and even open ceremonies.

Humanlike robots are still very limited in terms of what they are capable of doing. Comprehending speech is still far from a level of conducting a full conversation and they are only capable of discussing predetermined subjects. To make them affordable their price will need to come down significantly while making them fill a critical household need. Reducing the fabrication cost will require reaching mass production levels and standardization of their operating system and parts. As robots become more useful and safe to operate, they will increasingly be used as helpers, possibly replacing nannies and healthcare personnel, or act as providers of other human-related services.

2. DEVELOPMENT OF HUMANLIKE ROBOTS AS INTELLIGENT MACHINE

As advances in making humanlike robots will enable them to perform more critical tasks they are expected to become part of our daily life in the form of household appliances or even companions. However, the realization of truly humanlike machines is expected to raise ethical questions and concerns [Bar-Cohen and Hanson, 2009]. As opposed to other machines that improve our lives, this technology will also pose challenges that need attention and if we are not sufficiently careful they may even hurt us. Beside the potential accidents, deliberate harm, or use of robots to commit crimes, they may pose danger when given direct access to our intimate and confidential information and possibly making it public or using the information against us. Addressing the related concerns requires careful attention from the developers and the companies that will seek to commercialize them. Science fiction movies, literature, and homepages on the Internet are creating an exaggerated picture of the potential dangers that may result from developing humanlike robots. While we may be many years away from realizing the fictional capabilities there are realistic possibilities that will need to be addressed as these robots development evolves. Efforts by researchers in the field of robotic are already underway to study the possible negative issues and to find ways to address them by establishing codes of ethics as well as guidelines and algorithms for ethical use of AI in making robots. To maintain the freedom to develop such robots, these efforts are important to avoid having lawmakers impose unfavorable laws that may restrict the development of humanlike robots. For this purpose, boundaries are being sought for human-robot interactions before super-intelligent robots become capable beyond our control. The emphasis is on ensuring that humans maintain control of robots, prevent their illegal use, protect the data that robots acquire, and establish methods of clearly identifying such robots. While the concern of having such robots reaching human intelligence level, the fear of these robots becoming a threat to humanity is likely decades away. Still, it doesn't mean that we shouldn't bother considering this issue now in preparation for such possibility by adjusting the way our robots are built to prevent them from being sociopathic and to make sure that they are helpful and good.

Generally, humanlike robots are still very far from emulating the full capability of a real person even though some of the developed ones are quite capable and look very close to a real human. The reported robots [Bar-Cohen and Hanson, 2009] are capable of executing relatively few functions and specific tasks. For example, the use of AI is already enabling facial recognition and building robots with personality and behavioral differences between the produced duplicates of the particular robots. In spite of the progress, there are still many challenges to the capability of humanlike robots. These include making a robot that can walk fast in a crowd without hitting anyone, perform a comprehensive conversation with humans on a broad range of subjects, and operate over extended period of time without the need to recharge its batteries. To develop low cost robots in large production volume there is a need for standard hardware and software platforms that will have inter-changeable parts and with system compatibility similar to personal computers. Thus, designers will be able to avoid the need to start from scratch each time they produce a new robot. Further, there is a need to increase the response speed and the reaction to changes in the environment. This will require the use of many miniature light weight sensors with distributed processing capability as well as fast high power density actuators.

3. EAP ACTUATORS AS ARTIFICIAL MUSCLES

Actuators in robots are emulating the operation of muscles moving their appendages and mobilizing their body. The actuators that are used include: electric, pneumatic, hydraulic, piezoelectric, shape memory alloys or ultrasonic motors. Electric motors are widely used to move components of humanlike robots but they behave differently than our natural muscles with a totally different operation mechanism. Specifically, DC and AC type electromagnetic motors are used with gears to compromise speed of rotation for torque capability. In contrast to motors, natural muscles are compliant and exhibit linear behavior [Full and Meijer, 2004]. It is important to emulate these capabilities of muscles since they address key requirements in controlling the mechanical operation of robots. The closest to have the potential to emulate natural muscles are the electroactive polymers (EAP). These materials have emerged in recent years as biologically inspired actuation materials and they gained the name "artificial muscles" [Bar-Cohen., 2004; Hanson, 2004]. In the 1990s, the developed materials were quite limited in their ability to move or lift objects. Recognizing the need for international cooperation among the developers, users, and potential sponsors, the author initiated and organized in March 1999 the first annual EAPAD Conference. At the opening of this conference, he posed a challenge to the worldwide researchers and engineers to develop a robotic arm that is actuated by artificial muscles to win an armwrestling match against a human opponent [http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-armwrestling.htm].

In 2005, three groups that consisted of scientists and engineering students were ready with EAP actuated robotic arms for the first armwrestling match against a human. The contest was held on March 7, 2005, at San Diego, CA, as part of this annual SPIE's EAPAD Conference and it was organized with assistance from the United States ArmSports who provided the wrestling table and a representative as one of the contest judges. The human opponent was a 17-years old straight-A high school female student from San Diego [http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/amerah/the-human-opponent.htm], whose name is Panna Felsen. Even though the student won in all the three wrestling matches that took place, this has been a very important milestone for the field. Since the currently developed robotic arms with EAP actuators are not at a level that allows winning against humans, the author changed the focus of the near future contests. As of 2006, the contest was turned to measuring the arms capability and comparing the data of the competing arms. A fixture (see **Figure 1**) was made jointly by individuals from UCLA and the author's group at JPL allowing for measuring the speed and pulling force capability of the arms. The test fixture was equipped with a pulling cable that was connected through the fixture to a force gauge at the other end. To gauge the speed a 0.5-kg weight was mounted on the cable which has to be lifted to the top of the fixture and the time to reach the top is measured. To establish a human reference baseline data, Panna Felsen was invited to the event and her capability was measured. The 2006 results of three participating arms have shown about two orders of magnitude slower and weaker force capability than the student. In a future conference, once advances in developing such arms reach sufficiently high level, a professional wrestler will be invited for the next human/machine wrestling match.

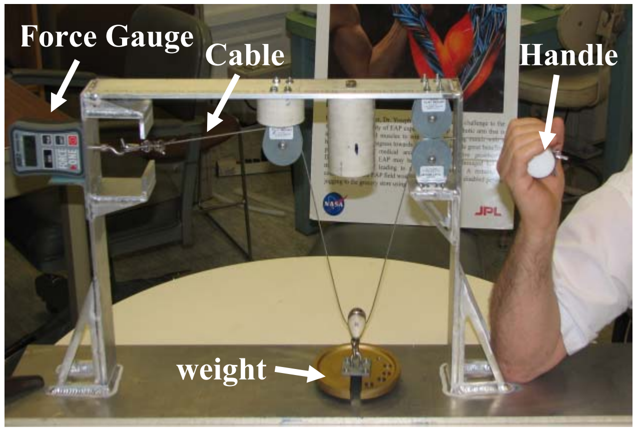

Figure 1: The fixture that is used to test the force and speed of the EAP actuated robotic arms

There are many known EAP materials and, according to their activation mechanism, they were divided by the author to two groups: *electronic* (also known as the *field activated)* and *ionic* [Bar-Cohen, 2004]. Currently, the EAP materials that have the greatest readiness for being used to produce actuators of robotic mechanisms are the dielectric elastomer EAP. Since the actuation does not involve diffusion of charge species, as in *ionic* EAP, these materials respond fast in the range of milli-seconds. As *electronic* EAP they can hold the induced displacement while being operated under a DC voltage and this gives them even advantage over natural muscles since no energy is needed for holding part at a fixed position. Moreover, as opposed to the *ionic* EAP, they have a greater mechanical energy density and they can be activated in air with no major constraints. The dielectric elastomer EAP are made of low elastic stiffness polymers allowing them to generate large strain when subjected to an electrostatic field [Pelrine et al. 1998; Kornbluh et al. 2004; Zhongyang and Zhang, 2008]. Generally, high voltage levels (>100-V/μm) are required, which may be close to the breakdown level. In order to avoid impeding the generated strain their electrodes have to be highly compliant. The applied electric field results in a strain that is proportional to the square of the electric field and to the dielectric constant while inversely proportional to the elastic modulus. The required high activation field is the result of the low dielectric constant in polymers that, typically, is below 10. To address this issue two different approaches are used: a) making multilayered structure of thin films that are stacked to reach the required thickness (this is a method that is commonly used in piezoelectric ceramic actuators); and b) increasing the dielectric constant by forming a composite. Dielectric elastomer EAP actuators can generate significant strain reaching more than 100%. The applied field causes thickness contraction and lateral expansion. To produce linear actuators using dielectric elastomer films, scientists at SRI International rolled two elastomer layers with carbon based electrodes on both sides of one of the layers forming a cylindrical actuator [Kornluh et al. 2004]. Further modifications of their actuator design led to the development of the multifunctional electro-elastomer roll (MER). In this actuator highly prestrained dielectric elastomer are rolled around a compression spring [Pei, et al, 2004]. By selectively actuating only certain regions of the electrodes around the periphery of the actuator it can be made to bend as well as elongate.

Another concern associated with the use of such EAP materials is the required prestraining that over time is released due to creep degrading the actuator performance. To eliminating the need for prestrain the following solutions were applied:

Chemical solution: Researchers at Sungkyunkwan University, Korea, [Jung, et al, 2004] and at UCLA, USA, [Ha et al, 2006] developed promising methods that are based on specialized synthesizing dielectric elastomers. Ha and his coinvestigators [2006] at UCLA used an Interpenetrating Polymer Network (IPN) where tension in the network is balanced by compression. To form IPN thermally crosslinkable liquid additives were used including a difunctional acrylate (e.g., HDDA) and a trifunctional acrylate (e.g., TMPTMA).

Mechanical solution: Designing the actuator with a configuration that eliminates the need for prestrain was done by scientists at the University of Pisa, Italy, and EMPA, Switzerland. Capri and de Rossi, Italy, [2007] used a folded film structure to produce a contractile actuator. The film contraction along the folds resulting from the activation is harnessed in the stack form of this actuator. Further, in a recent study at EMPA, Switzerland, [Kovach and Düring, 2009] a method was developed for stacking thousands of thin layers of a dielectric elastomer to form effective actuator that generates contraction and does not require preload (**Figure 2**). Using this design, levels of 40% strain were measured using up to 40mm diameter and 100 mm long actuator.

Figure 2: Photographs of multilayered dielectric elastomer in passive (left) and activated states (right). Courtesy of Gabor Kovacs, EMPA Dübendorf, Switzerland.

4. CONCLUSION

Emulating the human appearance, functions and intelligence is the ultimate goal of the field of biomimetics as well as humans' efforts to reproduce ourselves in art and technology. Making humanlike robots involves developing machines that are the copy of human appearance and imitating our behavior as biological systems. Increasingly, such robots are becoming a reality as a result of recent technology advances [Bar-Cohen and Breazeal, 2003; Bar-Cohen 2005; Bar-Cohen and Hanson, 2009]. Tools such as finite element modeling, computer simulations, rapid image processing, graphic displays and animated simulations, as well as many others are allowing for making enormous progress towards producing life-like robots. There are still numerous challenges to producing humanlike robot. Overcoming these challenges requires multidisciplinary expertise that includes engineering, computational and material science, robotics, neuroscience, and biomechanics. This development need to be supported by progress in many related fields, including artificial intelligence, artificial muscles, artificial vision, speech synthesizers, mobility, control, and many others. As these robots become more useful in our life they may start appearing as a household appliance or our companions and probably a common sight in our future environment.

To support the development of humanlike robots that operate life-like there is a need for advances in making effective EAP materials in order to bring them to the functionality level that matches the performance of human muscles. As emerging EAP materials, there is a need to establish the scientific and engineering foundations to allow turning them to actuators-of-choice. This requires improving the understanding of the basic principles that drive them. Some of the needed scientific foundations involve having effective computational chemistry models, comprehensive material science, electro-mechanics analytical tools and material processing techniques. The development of the foundations necessitates gaining better understanding of the parameters that control their electro-activation behavior. In order to maximize the actuation capability and operation durability, effective processing techniques are being developed for their fabrication, shaping, and electroding. Methods of reliably characterizing the response of EAP materials are being developed and efforts are underway to create databases with documented material properties [see for example http://www.actuatorweb.org/]. To bring these materials to the level of application in daily use products will necessitate finding a niche application that addresses critical needs and hopefully the application to making humanlike robots will help advancing the commercialization of both technologies.

Generally, many science fiction movies have generated a horrible image of the possible consequences of having humanlike robots go out of control. While these are science fiction scenarios, there are realistic concerns of this technology and roboticists are currently making efforts to establish codes of ethics and guidelines to deal with the required action. As the technology evolves in making more lifelike robots and as improvements are made in advancing the capability of EAP the merging of the two fields offers exciting possibilities.

5. ACKNOWLEDGEMENT

Some of the research reported in this manuscript was conducted at the Jet Propulsion Laboratory (JPL), California Institute of Technology, under a contract with the National Aeronautics and Space Administration (NASA).

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