Humanlike robots – the upcoming revolution in robotics

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

Humans have always sought to imitate the human appearance, functions and intelligence. Human-like robots, which for many years have been a science fiction, are increasingly becoming an engineering reality resulting from the many advances in biologically inspired technologies. These biomimetic technologies include artificial intelligence, artificial vision and hearing as well as artificial muscles, also known as electroactive polymers (EAP). Robots, such as the vacuum cleaner Rumba and the robotic lawnmower, that don't have human shape, are already finding growing use in homes worldwide. As opposed to other human-made machines and devices, this technology raises also various questions and concerns and they need to be addressed as the technology advances. These include the need to prevent accidents, deliberate harm, or their use in crime. In this paper the state-of-the-art of the ultimate goal of biomimetics, the development of humanlike robots, the potentials and the challenges are reviewed.

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

1. INTRODUCTION

Over millions of years, Nature produced through the process of evolution an incredible pool of inventions that are solutions that work well and are durable. These inventions are serving as models for mimicking and inspiration and the field is known as biomimetics [Bar-Cohen, 2005]. From the early days of human civilization the value of these inventions was well recognized and it led to the development of many effective tools. Recent advances in technology are enabling a significant rise in seeking more complex possibilities of mimicking biology. Making humanlike robots is the ultimate challenge to biomimetics and it is exciting to point out that such robots are becoming incredibly more effective and sophisticated. As opposed to any other human made development, if the capability of these robots is advanced to the point that makes them very smart with self-identity and cognitive behavior they will not be just another tool anymore. Considering the fact that humanlike robots are based only on the first fifty years since intelligent machines started emerging, these robots have many limitations but their capability is still quite impressive [Bar-Cohen and Hanson, 2009]. As opposed to industrial robots that are used in production lines, which are fixed in place to perform fabrication and/or testing functions, humanlike robots are mobile with some that are autonomous and they are able to perform many functions that are lifelike. The mobility and autonomous operation of these robots are raising many concerns that need to be addressed before such robots cause harm to humans and/or properties. Predictions in the 1980s and 1990s suggested that by now such robots will become a house hold tool but the reality seems to have been significantly slower where the only commercial robots that found their way to homes is the vacuum cleaner called Roomba (made by iRobot). This robot vacuums the floor while traveling from one end of the house to the other avoiding obstacles and staying within defined bounds. It was already sold in millions of units but it only has a disk shape. 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 human, as well as humanlike robots with significant similarity to humans [Bar-Cohen and Hanson, 2009].

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. Many of the leading manufacturers in Japan are already producing prototypes and investigating the potential markets for humanoids. Examples of the humanoids that are being developed include Asimo (made by Honda), HOAP robots (made by Fujitsu), and the Partner Robots (made by Toyota). 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

Biomimetics and Bioinspiration, edited by Raúl J. Martín-Palma, Akhlesh Lakhtakia, Proc. of SPIE Vol. 7401, 740102 · © 2009 SPIE · CCC code: 0277-786X/09/$18 · doi: 10.1117/12.824088

their batteries has to be recharge after about an hour or less depending on the model and the performed tasks. The developed robots are mostly being made towards establishing consumer and industrial markets. Eventually, even though these robots are still far from becoming a household machine, the market that they are expected to generate is estimated to reach billions of dollars. Sony was a leading developer of such robots and even started commercializing its child-size robot QRIO (Quest for curiosity). However, on January 26, 2006 it announced the cancellation of any further development of its humanoid robots. It is interesting that analogously to nature there is also in marketing the rule of the survival of the fittest holds where not every product is a success and the QRIO is one of the a loser in the "natural selection" process.

Worldwide, many humanoids and humanlike robots have already been developed in many countries. The main applications for which these robots are being considered include health-care, entertainment, home or office security, and military [Bar-Cohen and Hanson, 2009]. Robots that appear as lifelike humans are already being made to operate like hospital workers, receptionists, guards, and more, and they can speak in various languages (generally with a vocabulary of about 1,000 words or less), dance to the sound of music, and play musical instruments. While still limited in number, humanlike robots are increasingly being developed and mostly in Japan, Korea and China. Researchers and engineers in other counties are also contributing to the development of this technology. In Japan, besides economical factors, the development of humanlike robots is motivated by the significant reduction in population due to their record low birthrate and their longest lifespan worldwide. To support elderly, disabled or patients in rehabilitation, these robots are being developed to provide monitoring assistance without break including night and day operation. Having the second-largest economy in the world makes employers in Japan greatly concerned about their future inability to find low-level skill employees that would perform dirty, dangerous, and physically demanding jobs.

While humanoid robots are made by many companies in Japan, the development of humanlike robots, which are still quite a challenge, is done mostly at academic and research institutes. One of issues that are facing the developers of these robots, particularly in Western cultures, is phobia that may be related to what is known as the Uncanny Valley Hypothesis [Bar-Cohen and Hanson, 2009]. Generally, humans have a tendency to be excited about robots that are made with increasing similarity to humans and forgiving to limitation in appearance and performance. However, the closer these robots will be made to look and behave similar to humans the more critical humans are expected to act towards their deficiencies. Humanlike robots are still capable of performing quite limited number of tasks and functions. Comprehending speech is still far from the 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. As robots become more useful and safe to operate, they will increasingly be used as helpers and providers of various human-related services.

2. HISTORICAL PERSPECTIVE OF HUMANLIKE ROBOTS

The word Robot is defined as machine that looks like a human and performs humanlike complex tasks such as speaking or walking. Generally, it refers to an electro-mechanical machine with biomimetic characteristics including the ability to manipulate objects, sensing the environment and having certain degree of intelligence. The word itself is based on the Czech word *robota* that means hard work or slavery. Humanlike machines were part of the ancient Greeks legend of the mechanical helpers of the god Hephaestus that were in the form of strong, vocal and intelligent living young women made of metal [Rosheim, 1994]. Another humanlike imaginary creation is the 16^{th} Century Jewish story of the clay made Golem who was produced to act as a servant. When listing imaginary humanlike creatures one of the most famous fiction characters is the monster from Mary Shelley's novel *Frankenstein* [1818]. In this novel, the scientist Victor Frankenstein used human body parts to create a monster that he brought him to life. It is interesting to note that both fiction characters, the Golem and Frankenstein, were made as living humanlike creatures and the end result has been violent with disastrous consequences to their creators. The lessons learned from these legends suggests that there is potential evil that results if a humanlike form is created and given freedom to act without control or restrictions.

Given the complexity of making humanlike machines or robots this technology has been slow to emerge. Leonardo da Vinci in 1495 (estimate) made the first sketch of a humanlike machine in the form of a mechanical knight that could sit, wave its arms, and move its head via a flexible neck while opening and closing its jaw [Rosheim, 1996]. Only in the 17^{th} Century physical machines started emerging that perform humanlike tasks – these machines were driven by mechanical energy that was stored in a spring. Examples include the "The Flute Player" that was produced by the French engineer Jacques de Vaucanson in 1737 and the “Writer” that was made by the Swiss clockmaker Jacquet-Droz and completed in 1772. The era of robotics as we know it today where the machine is equipped with artificial intelligence has began in 1946 with the first introduction of the digital computer, the ENIAC computer, which was the first large-scale general-purpose electronic computer [McCartney 1999]. The first time that the possibility of building thinking and learning machines was raised was in 1950 [Turing, 1950]. Progress in developing powerful microprocessors with high computation speed, very large memory, wide communication bandwidth, and more effective software tools made the most impact on the development of intelligent robots. With the advancements in microelectronics and intelligent software more sophisticated robots have been emerging with concepts and methodologies that are inspired and guided by nature [Arkin 1998; Bar-Cohen and Breazeal, 2003; Bar-Cohen and Hanson, 2009; Gould, 1982].

With the advances in technology, humanlike robots are increasingly becoming easier to make as lifelike using effective autonomous operation algorithms, humanlike materials, and the capability to emulate the movement and functionality (seeing, hearing, smelling, etc.) of humans. Using state of the art microprocessors, materials, sensors, software, and many other technologies are leading to increasingly more capable robots. These advances are allowing them to perceive, interpret, respond, and adapt to their environment. Robotic products are already being developed for entertainment, education, healthcare, home security, military, and many others. Currently, entertainment applications are the most beneficiary of this technology where humanlike robotic toys are commercially available in many stores. Further, industry has begun to collaborate with scientists to make their characters in movies appear more realistic and to move more like people. Also, robotics researchers are increasingly collaborating with artists to make their robots appear more expressive and believable.

3. MAKING A HUMANLIKE ROBOT

Developing a humanlike robot involves copying the appearance of humans as well as emulating the capabilities, expression of emotions and possibly even having thoughts. Making such robots involves advances in many disciplines including mechanical and electrical engineering, materials science, computer science, artificial intelligence, and control. To make such smart machines that look and act like a human there is a need to integrate capabilities that are at the cutting edge of the related technology [Bar-Cohen and Breazeal, 2003; Bar-Cohen and Hanson, 2009]. The materials to be used need to be resilient, lightweight and multifunctional. Further, the mobility system that is used needs to allow walking via two legs and maintain stability while able to traverse complex terrains (e.g. climb stairs and avoid obstacles). These robots need sensors to visualize the train, hear sound, as well as sense touch, pressure and temperature. The robots need to use light batteries and/or generator for power that can be operated over a long time without recharge. In addition, the robots need to interpret the information that is measured by the sensors to perceive and be aware of the surrounding terrain and to sense hazards and risks. Humanlike robots need to have effective control and artificial intelligence algorithms in order to be operated like humans and interact with its environment and humans [Plantec, 2003]. The produced robots need to have body parts and related functions similar to a human as much as possible. The head is one of the most important parts - it identifies the robot and contains critical sensors that allow assuring its safe operation and interaction with the surrounding. Increasingly, the body, facial and verbal expressions are synchronized to project a lifelike appearance and behavior [Hanson, 2005; Bar-Cohen and Hanson, 2009]. To appear lifelike, the body of the robot needs to be covered with a skin that looks and feels like a living person. This requires that the skin is highly elastic to make facial expressions without residual deformation (see example in **Figure 1**).

The rest of the robot body needs to be made in the general appearance of human too where hands and legs need to operate similar to humans’ natural appendages. Advances in technology have made walking on two legs and the maintenance of dynamic stability an established capability of many biped humanoids and humanlike robots [Raibert, 1984]. To act in a natural way, sensors are mounted on the legs, arms and hands including pressure sensors to determine the grip level, and touch sensors to interpret tactile impressions. The success in emulating the appearance and operation of the human hands and legs is already benefitting disabled people with highly effective and lifelike prosthetics. In addition to artificial limbs there is also development of walking chairs as replacement to wheel chairs where the user can traverse in areas that are not flat including steps.

Generally, actuators are used to emulate human muscles and allow robots mobility and movement of their appendages and other parts and mechanisms. The actuators that are used include: electric, pneumatic, hydraulic, piezoelectric, shape memory alloys and ultrasonic motors. Electric motors are widely used to perform the movements but they behave very differently from human muscles and have a totally different operation mechanism. The major difference is that natural muscles operate as compliant and linear actuators [Full and Meijer, 2004] and it is necessary to emulate them to operate a lifelike robot. The recently emerged electroactive polymers (EAP) are the closest to emulate natural muscles and for this capability they gained the name "artificial muscles" [Bar-Cohen, 2004]. Most of the currently known EAP materials were developed in the 1990s but they still exhibit low actuation forces. Recognizing the need for international cooperation the author initiated and organized in March 1999 the first annual international EAP Actuators and Devices (EAPAD) Conference [Bar-Cohen, 1999]. The EAPAD Conference is held by the technical society SPIE as part of its annual Smart Structures and Materials Symposium. At the opening of the first Conference, the author posed a challenge to the worldwide scientists and engineers to develop a robotic arm that is actuated by artificial muscles to win an armwrestling match against a human opponent. The icon of the challenge is shown in **Figure 2** illustrating the wrestling of a human arm with a robotic one driven by artificial muscles.

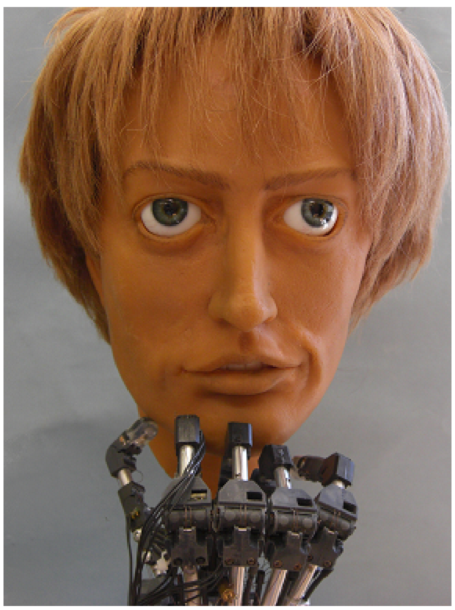

Figure 1: Humanlike robot head that is capable of smiling and eye movements. Photographed at JPL by the author where the head was made by David Hanson, Hanson Robotics, and the hand by Graham Whitley, Sheffield Hallam University, UK.

Figure 2: The icon of the armwrestling challenge for artificial muscles match against human.

The first contest of arm-wrestling with human (17-year old high school female student) was held on March 7, 2005, as part of the EAP-in-Action Session of the SPIE's EAPAD Conference. Three robotic arms participated in the contest and the girl won against all the arms (see **Figure 3**) that participated. For the 2nd Artificial Muscles Armwrestling Contest that was held on Feb. 27, 2006, a test fixture was used to measure the arms speed and force. The results have shown two orders of magnitude lower performance of the arms compared to the student capability that was measured to serve as a baseline. 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.

To allow "smart" operation of humanlike robots, artificial intelligence (AI) is being used allowing for knowledge capture, representation and reasoning, reasoning under uncertainty, planning, vision, face and feature tracking, language processing, mapping and navigation, natural language processing, and machine learning. Even though AI led to enormous successes in making smart computer controlled systems, still the capability is far from resembling the human intelligence. The latest advances in technology have led to robots that look very much like humans but mostly able to perform limited functions. Some the advances include self improvement through learning as well as autonomous operation and self-diagnostics. In the future, these robots may even be designed to go on their own to a selected maintenance facility for periodic checkups and to be repaired as needed. In case of damage, future robots may be made of biomimetic materials that are capable of self-healing. In order to take advantage of their capability while they still have limited intelligent operation there is a development of remotely operated robots in the form of telepresence. An example of such a robot is the Robonaut (i.e., robotic astronaut) that is being developed at the NASA Johnson Space Center (JSC), Houston, Texas, USA, where the robot can mirror the physical movements of the upper section of the human body (see **Figure 4)**.

The incorporation of voice synthesis, detection and recognition for interaction between humanlike robots and humans [Breazeal 2002; Bar-Cohen and Breazeal 2003; Hanson 2005] is enabling robots to communicate verbally, expressing emotions while making eye contact and facial expressions, as well as responding to emotional and verbal cues. These capabilities are making such robots appear and behave more social with the capability of emotional adaptation since they interact and communicate with people in ways that are familiar to humans without the need for training. The conversations that can currently take place with robots are limited in vocabulary and content but significant amount of research is dedicated to the development of machine capability to understand human conversation.

Figure 3: The robotic arm driven by artificial muscles, made by Virginia Tech students, is being prepared for the 2005 match against the human opponent, Panna Felsen, a 17-years old student from San Diego.

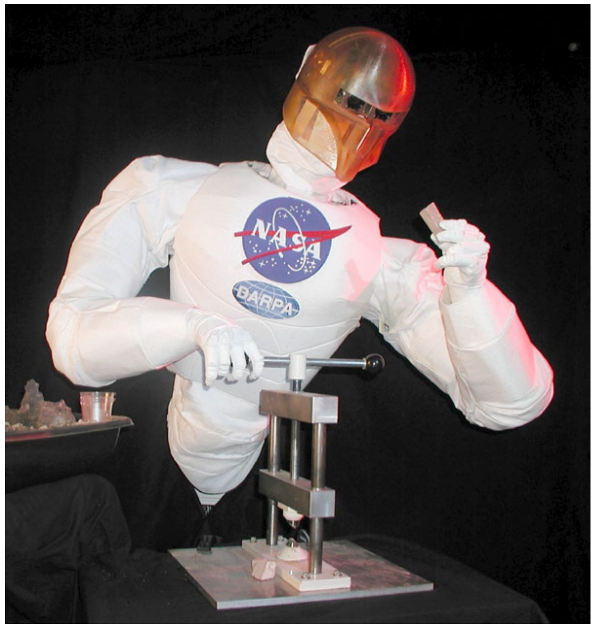

Figure 4: The Robonaut is remotely controlled to perform physical tasks by mirroring the actions of a human for potential future NASA missions. Courtesy of NASA Johnson Space Center.

4. HUMANLIKE ROBOTS AS INTELLIGENT MACHINE – THE RISKS AND BENEFITS

Humanlike robots are expected to perform increasingly more critical tasks as an essential part of our future household to greatly help improve our life. They may assist us from birth to very old age including performing the various functions that are done for us by other human beings. However, in contrast to the other instruments and devices that we are using today, these smart mobile machines will also pose great risks to us raising ethical and many other concerns [Bar-Cohen and Hanson, 2009]. Beside the potential accidents, deliberate harm, or use of robots to commit crimes, they may use our most intimate and confidential information to which they will have direct access and possibly making it public or use it against us. For many years, science fiction literature and movies have been suggesting such potential dangers. While it are still far very far from being realized soon scientist and engineers in robotics are already studying the possible negative issues and seeking ways to address them. Codes of ethics, guidelines and algorithms are being established for making ethical and safe robots. These efforts are critical not only out of the concern of the emergence of such robots but also to avoid seeing lawmakers impose laws that will restrict the development of such robots. The key to the current efforts is to assure that the robots are maintained under human control and prevented from illegal acts.

5. POTENTIALS AND CHALLENGES

While current humanlike robots already have impressive capabilities, they are still far from emulating the full capability of a real person and they only can perform limited functions and mostly execute specific tasks. They can interpret facial, have personalized behavior as well as walk or dancing in a humanlike form but the developers are still faced with enormous challenges. These include conducting a comprehensive conversation with human on a broad range of subjects, walking fast in a crowd without hitting anyone, operating over an extended period of time without recharge and many others. Every component of these robots will need further improvements. The ability of a robot to conduct a comprehensive conversation will require ability to recognize and "understand" significantly more words than they are able today. Development in biomimetics may lead to intelligent robots that can become our peers offering unmatched benefits in terms of functionality and intellectual support. One may envision such a robot being used as companions to elderly allowing living till a very old age while assisting them in every aspect including repairs, support, medical emergencies and others. Making a humanlike robot self-aware of the consequences of its acts and having it operate with rules of "right" and "wrong" may be highly difficult task, and some even claim that this is an impossible task. As we get used to seeing humanlike robots as helpers and find them more useful in performing increasing numbers of critical task, the author believes that we will be more receptive to having them in our household.

5. CONCLUSION

The ultimate goal of the field of biomimetics and humans' efforts to reproduce ourselves is to emulating our appearance, functions and intelligence in a humanlike robot form. Making such robots requires developing machines that are the copy of our appearance while also imitating our behavior as biological systems. Increasingly, such robots are becoming a reality as a result of recent technology advances. Various tools that are available today, including finite element modeling, computer simulations, rapid image processing, and many others are allowing enormous progress towards producing lifelike robots. There are still numerous challenges to producing such robot and overcoming them requires multidisciplinary expertise that includes engineering, computational and material science, robotics, neuroscience, and biomechanics. This development need to be supported by progress in many biomimetic 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 in our home and office and probably become a common sight in our future environment.

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 already making efforts to establish codes of ethics and guidelines to deal with the required action.

The increasing abilities of humanlike robots are leading to exciting capabilities where, for example, robots are developed in Japan and the USA to assist recovering patients, elderly and other people who need physical or emotional support. As the technology evolves in making more lifelike robots and as improvements are made in advancing the capability of these robots they are offering future possibilities that may now be considered science fiction.

6. 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).

7. REFERENCES

Arkin R., *Behavior-Based Robotics*. MIT Press, Cambridge, MA (1989)

Bar-Cohen, Y., (Ed.), *Proceedings of the 1st SPIE's Electroactive Polymer Actuators and Devices (EAPAD) Conf.*, 6th Smart Structures and Materials Symposium, SPIE Proc. Vol. 3669, (1999), pp. 1-414.

Bar-Cohen Y., and C. Breazeal (Eds.), *Biologically-Inspired Intelligent Robots*, SPIE Press, Bellingham, Washington, Vol. PM122, ISBN 0-8194-4872-9 (May 2003), pp. 1-393.

Bar-Cohen Y. (Ed.), *Electroactive Polymer (EAP) Actuators as Artificial Muscles - Reality, Potential and Challenges*, 2nd Edition, ISBN 0-8194-5297-1, SPIE Press, Bellingham, Washington, Vol. PM136, (March 2004), pp. 1-765

Bar-Cohen Y., (Ed.), *Biomimetics - Biologically Inspired Technologies*, CRC Press, Boca Raton, FL, ISBN 0849331633, (November 2005), pp. 1-527.

Bar-Cohen Y., and D. Hanson, *The Coming Robot Revolution - Expectations and Fears About Emerging Intelligent, Humanlike Machines*, Springer, New York, ISBN: 978-0-387-85348-2, (2009).

Full R. J., and K. Meijir, "Metrics of Natural Muscle Function," Chapter 3 in [Bar-Cohen, 2004], pp. 73-89.

Gould, J., *Ethology*, Norton, (1982)

Hanson D., "Robotic Biomimesis of Intelligent Mobility, Manipulation and Expression," Chapter 6 in [Bar-Cohen, 2005], pp. 177-200

McCartney S., *ENIAC: The Triumphs and Tragedies of the World's First Computer,* Walker & Company, New York, (1999)

Plantec P. M., and R. Kurzwell (Foreword), "Virtual Humans: A Build-It-Yourself Kit, Complete With Software and Step-By-Step Instructions," ISBN-10: 0814472214, ISBN-13: 978-0814472217, AMACOM/American Management Association; (2003).

Raibert M., *Legged Robots that Balance*, Cambridge, MA: MIT Press, (1986).

Rosheim M. *Robot Evolution: The Development of Anthrobotics* Wiley, (1994)

Rosheim, M. "Leonardo's Lost Robot," *Journal of Leonardo Studies & Bibliography of Vinciana*, *Vol. IX*, *Accademia Leonardi Vinci* (September 1996): 99-110.
Shelley M., "Frankenstein," Publishers: Lackington, Hughes, Harding, Mavor & Jones, (1818),
Turing A.M, "Computing machinery and intelligence," *Mind*, 59, (1950), pp. 433-460.