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Humanlike robots – synthetically mimicking humans

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ABSTRACT

Nature inspired many inventions and the field of technology that is based on the mimicking or inspiration of nature is widely known as Biomimetics and it is increasingly leading to many new capabilities. There are numerous examples of biomimetic successes including the copying of fins for swimming, and the inspiration of the insects and birds flight. More and more commercial implementations of biomimetics are appearing and behaving lifelike and applications are emerging that are important to our daily life. Making humanlike robots is the ultimate challenge to biomimetics and, for many years, it was considered science fiction, but such robots are becoming an engineering reality. Advances in producing such robot are allowing them to perform impressive functions and tasks. The development of such robots involves addressing many challenges and is raising concerns that are related to fear of their application implications and potential ethical issues. In this paper, the state-of-the-art of humanlike robots, potential applications and challenges will be reviewed.

Introduction

Nature has always served as a model for humans' innovation and problems solving. These efforts have been intensified in recent years and it has grown to the level that many scientists and engineers are considering it as a field of research and development. This field is now widely known as Biomimetics and it involves learning from nature as well as copying, mimicking and being inspired by its principles, concepts, mechanisms, and designs [Benyus, 1998; Vincent, 2001; Bar-Cohen, 2005, and 2011a]. While Nature uses solutions that work and last, it is important to remember that the solutions are the result of the survival of the fittest and are not necessarily optimal for the required functions. Effectively, for a biological capability to last, all organisms need to do is to survive long enough to reproduce. The evolving capabilities are coded into the species' genes and are passed through self-replication from generation to generation. Using advances in science and technology, we are increasingly becoming more capable of understanding many of the mechanisms in Nature and implementing them in artificial forms. Scientists are systematically seeking rules, concepts, mechanisms and principles of biology to inspire new engineering possibilities including manufacturing, mechanisms, materials, processes, and algorithms.

Even though humans were familiar with many of Nature's inventions they have not always been adapted to their needs. Examples include the camouflage as an effective defense, which humans were quite familiar with from the many creatures that lived near their habitats. This suggests that more proactive efforts are needed to apply such inventions. It is interesting to note that even plants use camouflage to address their requirements and for example the color of unripe fruits is green to make them blend with the leaves color while the ripe fruits have quite visible colors. Further, plants consist of many other "inventions" and the most famous one is the adherence of seeds to animals' fur that led to the Velcro and the numerous applications including straps for clothing and electric-wires. Plants capability to distribute water evenly throughout their structure including the giant trees offers important model for imitation. Moreover, the roots of plants are able to lift heavy structures as well as break through rocks but the mimicking of these capabilities is quite a challenge [Bar-Cohen, 2005; and 2011a]

One may wonder if the tools and capabilities that were developed by humans over hundreds or thousand years ago were totally the result of humans' innovation or were mimicked from Nature. Obviously, biological creatures evolved over many millions of years before humans reached the level of intelligence that was sufficient to start producing tools. These tools resulted from the need to minimize the dependence on luck in finding food and resources. Observing Nature inspired many ideas and, as humans' capabilities improved, it became increasingly easier to mimic more sophisticated Nature inventions. The question is - which of the inventions and tools that resemble biological models and widely used by humans resulted of mimicking and which ones have just coincidental similarity? It is hard to believe that all human-made solutions were purely independent inventions ignoring what is commonly seen in their neighborhoods. For example, developing alternative to breast feeding was critical for the survival of the off-springs particularly in the cases of unavailability of the mothers. This life-critical need has most likely inspired the bottle with soft nipple to make humans' babies receptive to this alternative feeding form. Following a similar logic, the spider web may have inspired the development of the net, sieve, screen, woven fabric, wires, rope and many others. One cannot ignore the similarity of the spider web to the fishing net, the kitchen strainer, or even our clothing.

Our natural human form and behavior have always been fascinating to us and they have been the subject of art, literature, and science. Advances in materials, processes, artificial intelligence, speech synthesis, image and speech recognition, and many other capabilities are increasingly enabling producing robots with humanlike characteristics [Bar-Cohen and Breazeal, 2003; Bar-Cohen and Hanson 2009]. To make them lifelike there is enormous efforts to develop such key artificial features as the overall appearance, the skin covering, the actuation and mobility, as well as the required elements of artificial intelligence, vision, hearing, and others. Electroactive polymers (EAP), also known as artificial muscles, are becoming more effective actuators [Bar-Cohen, 2004; Bar-Cohen, 2011]. Moreover, they are being produced with capabilities that once were considered science fiction ideas including being sociable with the capability to express emotions verbally and facially [Breazeal, 2002; Bar-Cohen and Hanson 2009]. Robots with humanlike attributes are known by many names including; Humanoids, Androids, and Automatons [Bar-Cohen and Hanson 2009]. Depending on their degree of similarity to humans, the author has used the term Humanoid to describe robots that mimic the general appearance of humans having head, arms, and possibly legs and eyes. Such robots have for example a head that is shaped as a helmet and making them is much easier than exactly copying the external human form. On the other hand, Humanlike Robots are referred to robots that are designed to appear close to real humans and so great efforts are made to exactly copy the appearance and performance. It is more complex to make them and none is commercially available yet. The reported humanoids and the humanlike robots were mostly developed and produced in Japan, Korea and China, with very few in the USA [Bar-Cohen and Hanson, 2009].

Generally, robots are electro-mechanical machines that perform complex tasks and have humanlike features. The word was derived from *robota* that, in Czech, means compulsory labor, and it was first used in 1921 by in Karel Čapek's play *Rossum's Universal Robots*. The earliest approach to moving joints of figures has been the use of strings. Such figures are known as the marionettes and they were originated in the medieval times in France. A major step in the development of robots, as we know them today, has been the making of the first sketch for the production of a humanlike machine. This sketch was produced approximately in 1495 by Leonardo da Vinci [Rosheim, 1996]. The first producer of a physical machine that appears and acts like a human is the French engineer, Jacques de Vaucanson. In 1737, he produced the

"Flute Player" that is a life sized mechanical figure that played a flute. The figure was driven by mechanical energy that is stored in a key-wound spring.

The most important contribution to the emergence of "smart" robots has been the development of the digital computers, where the ENIAC computer made in 1946 is the first recorded one [McCartney 1999]. Next in the list of significant contributors has been the conception of machines that "think and learn" that was first documented by Turing [1950], later it became known as the 'Artificial Intelligence'. Other capabilities that were/are developed to produce lifelike robots include humanlike materials for the skin covering; actuators to emulate muscles, as well as sensors for vision and hearing.

Today's robots are controlled by high-speed, powerful, miniature microprocessors having very large memory that can be operated autonomously and updated wirelessly [Menzel and D'Aluisio, 2000]. Robotic products are already being used in entertainment, education, healthcare, military and many other fields. Also, robotics researchers are increasingly collaborating with artists to make their robots appear more believable.

Making a humanlike robot

The task of making a humanlike robot is complex and requires copying the human appearance and capabilities as well as making it sociable that communicates emotions and possibly thoughts [Bar-Cohen and Breazeal, 2003; Bar-Cohen and Hanson, 2009; Bar-Cohen 2011]. It requires lightweight, miniature and highly efficient actuators; sensors that provide information related to images, sound, position, contract and operation forces, and temperature; lightweight multifunctional materials; and power source with reasonable charge duration. The design and fabrication require skills in electromechanical engineering, materials science, and artificial intelligence. Just like in natural humans, the head defines the identity of the robot and, generally, it is equipped with sound and vision sensors for monitoring the interaction with humans and adjacent objects. To make a robot appear humanlike, skin is used that is highly elastic and does not sustain residual deformation (for an example of a robotic head with skin see **Figure 1**) [Hanson 2004]. Also, the hands, arms and legs of humanlike robots are designed to perform similar functions like natural appendages [Raibert, 1986] where actuators provide the equivalence to muscles. Emulating muscles is critical to operate robots lifelike and, therefore, they need to be compliant and act linearly [Full and Meijer, 2004]. The closest to resemble natural muscle is achieved using electroactive polymers (EAP), which are widely known as "artificial muscles" [Bar-Cohen, 2004; Bar-Cohen 2011]. Most of the EAP materials that are currently available have been developed in the 1990s. These materials gained enormous interest of many engineers and scientists however they are still far from meeting the need of high actuation force.

The making and control of "smart" humanlike robots is achieved by artificial intelligence algorithms that include planning, representation and reasoning, mapping and navigation, vision, face and feature tracking, language processing, natural language processing, machine learning, and knowledge capture, [Russell and Norvig, 2003]. While significant progress in the field of AI has been achieved in recent years, the capability of computer-controlled systems using AI is still far short from human intelligence and most humanlike robots are limited to performing specific and limited tasks for which they were designed.

The humanlike robots that are made today are far from what they are depicted in science fiction books and movies, i.e., robots with capabilities that significantly exceed humans. However, they are capable of performing impressive tasks including autonomous operation, self-learning, self-diagnostics, as well as, while looking directly in the eyes, converse with humans (up to about thousand words vocabulary) [Bar-Cohen and Hanson, 2009]. Given the limitation of the current AI, the capability of the autonomous robots is quite constrained in the number of functions that they can perform and, therefore, some are tele-operated by wireless control. An example of tele-operated robot is the Robonaut (i.e. robotic astronaut) that was developed at NASA Johnson Space Center (JSC), Houston, Texas, USA. In its first generation, it was designed to mirror the movements of the upper body of a human operator using control suit equipped with sensors (**Figure 2**). It is interesting to note that the Robonaut shown in **Figure 2** represents the second generation of its design and it is made to operate as an autonomous robot. This robot is currently being developed jointly with the car manufacturer General Motors (GM) to operate alongside humans in production lines.

Figure 1: Using artificial skin provides an identity to a humanlike head and allows it to make facial expressions (made by David Hanson, Hanson Robotics, and photographed at JPL by the author).

Figure 2: The Robonaut originally was developed as a tele-operated robot and it is currently being developed as an autonomous robot.

With today's technology, via the internet we have already got accustomed to the capability to remotely operate and conduct repairs on our computers. Performing tele-presence can be the next level of capability where physical tasks will be performed remotely with all the related implications and benefits. Potential applications of tele-operated humanlike robots may include remote surgery or performing physical functions that require the participation of an expert or a specific person without the need for his/her physical presence. One may imagine the possibility of full-body tele-operated robot that conducts hazardous tasks at extreme conditions without risk to the operator and without the need to travel to the remote site.

Making humanlike robots a commercially viable product that operates as our peers or becoming useful household appliances, will require making them perform valuable daily tasks that are quite easy for a human to do while extremely complex to instill into a robot. These tasks include for example cleaning, repairs, household maintenance or even safeguard houses and their perimeter. Significant research and development efforts are currently being made to allow such capabilities and they are done by both industry and academia. Some of the applications that are currently being considered for humanlike robots in Japan and the USA include assisting patients in rehabilitation, elderly in nursing homes and others who need physical or emotional support [Bar-Cohen and Hanson, 2009]. Robots with the ability to interact emotionally are being considered in such therapies as treating patients with fear of speaking in public, and to improve peoples' communication skills. Moreover, humanlike robots are already showing promise in treating children with autism, by stimulating communication and interaction skills in order to reduce the severity of the disorder [Fornia et al, 2007].

Ethics and concerns of humanlike robots

The efforts to increase the similarity of humans and robots as well as the effect on their being liked by humans have been addressed by the Japanese roboticist Masahiro Mori [1970]. He hypothesized that as the similarity increases, initially there is enthusiasm but as similarity increases it will turn to strong rejection and even dislike, until reaching very close similarity and then these robots will become more favored. The graphic illustration of this attitude towards robots became known as the Uncanny Valley hypothesis [Mori 1970] and it is represented as a dip on the curve of the likeness vs. similarity level. The fear of humanlike robots may be a natural one and related to our sensitivity to behavioral anomalies that may indicate an illness. This may be attributed to the sensitivity to genetic disorders as part of our nature as living creatures and the survival of the fittest. There might be a rise to an unconscious alarm of the potential impact on the gene pool. It is interesting to note that critics of Mori's hypothesis do not accept it as a fact and argue that it has never been proven by systematic experiments.

Science fiction literature, art and movies present a negative outlook for the entry of humanlike robots into humans' life raising great concerns of this technology [Bar-Cohen and Hanson 2009]. Some of the concerns are quite legitimate since such robots are potentially capable of causing harm and damage as well as raising ethical concerns. Their use may complicate our lives, if, for example, they are programmed to take part in criminal or terrorist activities. Operating them next to humans requires taking safety measures and there have already been recorded accidents where robots caused death to humans [Zinn et al., 2004]. Besides the physical danger of accidental or intentional harm to humans, they have the potential of replacing unskilled human labor and possibly make these laborers unemployable since robots have numerous advantages in cost, adaptability and controllability.

The rise in concern regarding the possible emergence of humanlike robots that act unethically is increasingly getting the attention of roboticists worldwide and efforts are already being made to establish rules of ethics related to the development of such robots [Bar-Cohen and Hanson, 2009]. One may illustrate the operation of roboticists within rules of ethics as similar to having human community operating in a world that is surrounded by valleys with very steep slopes. If effective fences are established next to the edges of the community, the members can get very close to the fence without the danger of falling. Similarly, operating within established rules of ethics will prevent the robotics community from encountering such danger as having the public demand establishing laws that will restrict the research and development freedom to develop humanlike robots.

Capabilities, challenges, and potentials

Robots that appear and perform like humans are being developed with great appearance similarity and impressive capabilities. Using artificial intelligence algorithms, these robots are making facial and voice recognition and, some of the sophisticated ones, have personalized behavior too. Among the sophisticated humanlike robots that were developed, there are ones that are capable of piped walking and dancing, understanding speech, as well as express and recognize emotions. However, making humanlike robots significantly more capable is a great challenge beyond the current state-of-the-art. Further, to become attractive commercial product possibly in the form of household appliance or a companion, many of the current capabilities of these robots will need to be improved and incorporated into multi-functional robots.

Major concerns of humanlike robots include safety to operate in the proximity of humans, potential non-obedience and unacceptable behavior, as well as the possibility of ethical issues. Making such robots self-aware of their actions and operating them as compliant with rules of right and wrong may be a great challenge and may be even impossible to accomplish. It is hoped that as they become more useful household helpers with the ability to perform critical tasks, they would become attractive household product. Hopefully, by that time the key issues related to the robots behavior will be addressed effectively.

The technology is still at the level that new roboticists who seek to become developers of such robots, effective, need to start from scratch and to be able to develop all the required hardware and software. This situation hampers the participation of greater number of experts from other fields of science and engineering and it reminds us of the early days of computer software. It is essential to reach standardization of the related hardware and software tools and components as well as having greater compatibility and interchangeability. This will help getting faster and greater development in this field resulting from the entry of greater number of specialists that will be able to focus on contributing in their areas of expertise as well as minimize the cost that involves with their effort.

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