IV Conferencia Panamericana de END
Buenos Aires – Octubre 2007

AAENDE
Asociación Argentina de Ensayos No Destructivos y Estructurales

Human-like robotic inspectors - science fiction and reality

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Abstract
Imagine seeing an inspector working on an aircraft conducting NDE where suddenly you get the feeling that something is weird – this is not a real person but rather it is a humanlike robot. Your first reaction would probably be "it's unbelievable but this person looks so real" just as you would react to an artificial flower that is a good imitation. But, as opposed to a flower where you can touch to find out if it is real, here you will have to rely on your senses to confirm if your suspicion is founded. This science fiction scenario could become a reality at the current trend in developing robots. Terms such as artificial intelligence, artificial muscles, artificial vision and numerous others are increasingly becoming common engineering tools. Further, robots that operate and behave similar to humans are being developed with incredible similarity and amazing capabilities. Autonomous humanlike robots can potentially address the need to inspect structures with configuration that are not predetermined. The operation of such robots may take place at harsh or hazardous environments that are too dangerous for human presence. The state-of-the-art of making such robots will be reviewed and discussed in this paper.

1. Introduction

For many years, the trend has been to automate NDE processes in order to increase the efficiency of performing redundant tests. For this purpose, systems were developed to deal with specific production-line requirements. Realizing that some parts, particularly in field conditions, are too complex to handle by a simple automatic system led to the emergence of robotic mechanisms [Bar-Cohen, 2000]. Aircraft inspection has benefited from advances in robotic technology where manipulators and crawlers are now commercially available for rapid and reliable inspection tasks. At JPL (part of NASA), a multifunctional automated crawling system (MACS) was developed to simplify the mechanisms of scanning that are used in the field. Thus, a novel mobility platform was established onto which various types of board level NDE instruments can be mounted (see Figure 1). This crawler was inspired by biology - it uses two legs to "walk" on structures while adhering to wall surfaces similar to gecko. While this and other advancements were made to improve the speed and reliability of the inspection, having an on-site human operator is critically needed to assure the reliable operation of these robots. Making a robot having humanlike characteristics that autonomously performs NDE tasks can make significant impact on the field but it is still a challenge. With the current trend in technology such a possibility may not be a too distant reality.

Generally, the field of robotics is very much inspired by concepts from biology where many of nature's inventions are mimicked or adapted. Thru evolution of billions of years, nature addressed its challenges by trial and error "experiments" and came up with solutions/inventions that work well and last. For its evolution, nature employs principles of physics, chemistry, mechanical engineering, materials science, and many other fields of science and engineering. Biologically inspired technologies (also known as biomimetics) such as artificial intelligence, artificial muscles, artificial vision and numerous others are increasingly becoming common engineering tools [Bar-Cohen, 2005]. Making an inspector that is a humanlike robot that operates autonomously can be an ultimate NDE goal for biomimetics. Such robots can potentially inspect structures with configuration that are not predetermined, reach hard to access areas of structures, operate over a long time without a break, and they can be designed to operate at harsh or hazardous environments that are too dangerous for human presence. The emergence of Electroactive Polymers (EAP) materials [Bar-Cohen, 2004], which gained the moniker artificial muscles, gave a boost to the development of biomimetic application including humanlike robots [Bar-Cohen and Breazeal, 2003; Bar-Cohen, 2008].

FIGURE 1: MACS is a two-legged crawler that adheres to surfaces walking imitating the gecko. Herein, it is shown crawling on the C-5 aircraft [Bar -Cohen, 2000].

Searching the internet under the keyword robots would identify many links to reports that cover research and development projects related to robots that are equipped with biologically inspired features. The entertainment and toy industries have greatly benefited from advances in this technology. Further, robots are increasingly being used in movies showing creatures with realistic behavior and examples include AI, Bicentennial Man, Blade Runners and iRobot. Visiting toy stores one can easily see how far the technology progressed in making inexpensive toys that imitate biology – such store displays include frogs that swim in a fish bawl or dogs that walk back and forth or even bark. Operating robots that emulate the functions and performance of humans or animals involves the use of actuators and mechanisms with state-of-the-art capabilities. Upper-end robots and toys are becoming increasingly sophisticated allowing them to walk and talk. Some of them are also able to operate autonomously and can be remotely reprogrammed to change the characteristic behavior. As this technology evolves it is becoming more likely to believe that in the future humanlike robots may be developed to operate as artificial inspectors and perform tasks that are highly reliability and very repeatable with extremely low probability of errors and capable of working continuously and tirelessly. In spite of the success in making robots that mimic biology there is still a large gap between the performance of robots and nature creatures. The required technology is multidisciplinary involves the need for actuators that emulate muscles, smart control algorithms that involve effective artificial intelligence methodologies as well as many other sophisticated capabilities.

2. Nature as a biologically-inspiring model

Nature has always served as a model for mimicking and inspiration to humans in their desire to improve their life [Bar-Cohen, 2005]. By adapting mechanisms and capabilities from nature, scientific approaches have helped humans understand the related phenomena and the associated principles in order to engineer novel devices and improve their capability. This field of biomimetics is increasingly involved with emerging subjects of science and engineering and it represents the studies, imitation and inspiration of nature's methods, designs and processes. Biomimetics can offer new concepts for NDE and ideas have implemented in walking machines such as the crawler that is shown in Figure 1 [Bar-Cohen, 2000]. On the other hand, there are numerous examples where NDE is far lagging behind nature capabilities including, for example, the transducers that are used in ultrasonics compared to the capability of natural ears. Hearing involves far broader dB sensitivity and spectral bandwidth, ability to sense both the phase and amplitude analysis with capability to detect sound levels that are way below the background noise as well as operating in very noisy environments.

Biomimetics has an important role in making user friendly instruments and operating instructions. For example it is very clear which is a *male* or *female* connector, and also what does it means saw *teeth* or *dog-bone* test sample. Other terms derived from biology with their usage clearly understood includes the *heart* to suggest the center, the *head* as the beginning, and the *brain* to describe a computing system. The use of the terms *intelligent* or *smart* suggests the emulation of biological capabilities with a certain degree of feedback and decision making. In the world of computers and software many biological terms are commonly used to describe aspects of technology including *virus*, *worm*, *infection, quarantine, replicate*, and *hibernate* to name just a few.

3. Emerging humanlike robots

Making humanlike robots has become one of the exciting subsets of the field of robotics. Some of the leading countries at which such robots are being developed include Japan and Korea. In Japan, besides economical factors and potentials, the rush to make humanlike robots is motivated by the major depopulation problem that is resulting from their record low birthrate and from their having the longest lifespan of any group of people on Earth. For this country that has the second-largest economy in the world, great concerns have arisen regarding the future need for employees to staff factory floors and other low-paying jobs that require low-level skills and that may be dirty, dangerous, and physically demanding. Robots that appear as lifelike humans are emerging rapidly in Japan, and they are being made to look like and to operate as receptionists, night watchmen, hospital workers, guides, pets, and more. Numerous humanlike robots have already been reported and the development of many others is rapidly underway [http://www.androidworld.com/prod01.htm].

One of the most important aspects of making a humanlike robot is the human face. It provides the important characteristic of our identity and it is also our key communication tool. Thru facial and verbal expressions we communicate with others. An essential part of making robots that are barely distinguishable from realistic humans is the need to make the face as realistic as possible. The development of humanlike robots has become so sophisticated that robotic heads can now make highly realistic facial expressions, respond emotionally while conversing with humans. Recently, a polymer base material was developed, called Frubber, which is ideal for making facial expressions since it requires minimal force and power to produce natural-looking large deformations [Hanson, 2004]. Using this material, a robotic head that replicates the face of Einstein was developed that is fully expressive. Examples of the facial expressions that this robot can make are shown in Figure 2. The head can operate for hours using a small set of rechargeable batteries and consumed less than 10W at 6V [Hanson, 2005], thus dramatically reducing the required power. This low-power requirement enabled the head to function atop a walking robot body (made by KAIST, S. Korea). The produced Einstein-like robot was called "Albert Hubo," and it was made in celebration of the one-hundred-year anniversary of the Theory of Relativity. On November 19, 2005, this robot was demonstrated at the APEC summit that was held in Busan, South Korea, where it greeted and shook hands with numerous world leaders, including President George W. Bush (see Figure 3).

FIGURE 2: Using Frubber skin, a humanlike head of Albert Einstein that makes facial expressions was developed (Courtesy of David Hanson. Hanson Robotics, LLC)

FIGURE 3: President Bush is shaking the hand of the robot Albert Hubo on Nov. 19, 2005, at the APEC summit in Busan, South Korea. (Courtesy of David Hanson. Hanson Robotics, LLC)

There are already many examples of humanlike robots. For example, under the lead of Hiroshi Kobayashi, scientists at Tokyo University of Science made a cyber-receptionist female-like robot that behaves with an attitude and a temper [http://www.washingtonpost.com/wp-dyn/articles/A25394-2005Mar10.html]. This robot is equipped with voice-recognition technology, allowing it to make 700 verbal responses as well as various facial expressions, including joy, despair, surprise, and rage. At the World Expo, which was held in March 2005 just outside the city of Nagoya, Japan, visitors were able to leave their children in the care of a babysitter robot, NEC's PaPeRo, which recognizes the face of the individual children and, in case of an emergency, notifies their parents by cell phone. The security guard company Alsok has developed a Robot-cop that operates as a guard robot and can detect and deter intruders using sensors and paint guns, as well as put out fires and spot water leaks. Also, humanlike robots are being used to provide therapy to the elderly who are filling Japanese nursing homes at an alarming rate and very often fall prey to depression and loneliness. Besides helping to reduce stress and depression among the elderly, robots can provide them as much support and assistance as possible.

3.1 Making robots actuated by artificial muscles

Mimicking nature would immensely expand the collection and functionality of the robots allowing performance of tasks that are impossible with existing capabilities. The recently emerged electroactive polymers (EAP) that are also known as “artificial muscles” have added an important tool to biomimetics [Bar-Cohen, 2004 and 2005]. Generally, polymers have many attractive properties and characteristics including lightweight, inexpensive, fracture tolerant, and pliable. Further, they can be configured into almost any conceivable shape and their properties can be tailored to suit a broad range of requirements. Polymers that can be stimulated to change shape or size have been known for many years. The activation mechanism of such polymers include electric, chemical, pneumatic, optical, and magnetic. Electrical excitation is one of the most attractive stimulators that can produce elastic deformation in polymers. The convenience and the practicality of electrical stimulation and the recent improvement in capabilities made EAP materials one of the most attractive among the mechanical responsive polymers. As technology evolves, robots may be produced to take on such tasks as performing NDE procedures in hard to reach areas of aircraft structures.

To promote the development of effective EAP actuators, which could impact future development of humanlike robot, two platforms were developed. These platforms are available at the author’s lab at JPL and they include an Android head [see Figure 4 and a video at http://eap.jpl.nasa.gov] that can make facial expressions and a robotic hand with activatable joints. At present, conventional electric motors are producing the required deformations to make relevant 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 [see Figure 5 and video on http://eap.jpl.nasa.gov] is equipped with tandems 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.

The easy capability to produce EAP in various shapes and configurations can be exploited using such methods as stereolithography and ink-jet printing techniques. A polymer can be dissolved in a volatile solvent and ejected drop-by-drop onto various substrates. Such processing methods offer the potential of making robots in full 3D details including EAP actuators allowing rapid prototyping and quick mass production

[Chapter 14 in Bar-Cohen, 2001]. Making insect-like robots could help inspection hard to reach areas of an aircraft engine where the robot creature can be launched to conduct the inspection procedure and to download the data upon exiting.

FIGURE 4: An android head (Photographed at JPL) making facial expressions. This head is available at JPL as a testbed for EAP actuators. [Courtesy of D. Hanson, Hanson Robotics, LLC]

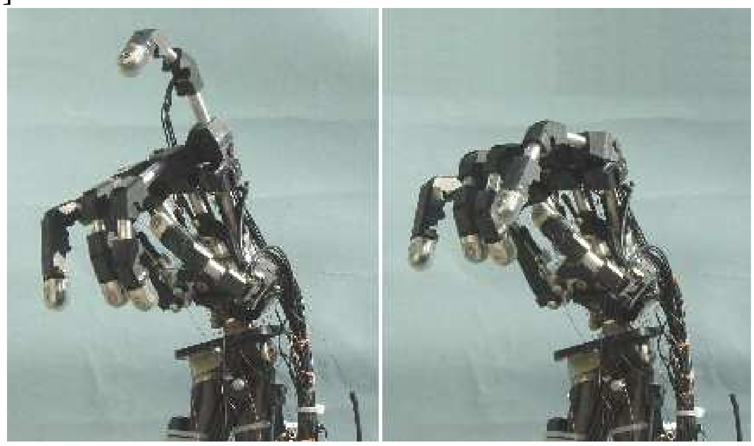

FIGURE 5: Robotic hand (Photographed at JPL) is available at JPL as a testbed for EAP actuators [Courtesy of Dr. Graham Whiteley, Sheffield Hallam U., UK.].

3.2 Remote presence

Remotely operated robots and simulators that involve virtual reality and the ability to “feel” distant 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 is developing haptic (tactile and force) feedback systems. Users of future NDE simulators may immerse themselves in the display medium while being connected thru haptic and tactile interfaces to allow them to "feel the inspection task" at the level of their fingers and toes. Thus, an expert can perform NDE procedures from the convenience of the office without having to be present at the operation site. The potential of making such a capability was enabled with such system concepts as the MEMICA (MEchanical MIrroring using Controlled stiffness and Actuators) [http://ndeaa.jpl.nasa.gov/nasa-nde/memica/memica.htm]. For this purpose, scientist at JPL and Rutgers University used Electro-Rheological Fluid (ERF) that 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 are conceived to be reflected to the users via proportional changes in ERF viscosity. Using such a system the user may be able to conduct procedures via virtual reality display while "feeling" the stiffness and forces that are involved. Once low cost systems are developed remote experts may use such a capability to perform distant inspection or student may perform virtual inspection of aircraft and other structures while being in a classroom.

4. The armwrestling challenge

EAP materials as artificial muscles are still in the emerging stages. In an effort to promote worldwide development towards the realization of the potential of EAP materials the author posed in 1999, an armwrestling challenge [http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-armwrestling.htm]. A graphic rendering of this challenge is illustrated in Figure 6. In posing this challenge, the author sought to see an EAP activated robotic arm win against human in a wrestling match to establish a baseline for the implementation of the advances in these materials. The first arm-wrestling contest of EAP driven robotic arms and human (17-year old female high school 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 these arms (an example of one of the wrestling sessions is shown in Figure 7).

FIGURE 6: Grand challenge for the development of EAP actuated robotics.

FIGURE 7: An EAP driven arm made by students from Virginia Tech and the human opponent, 17-year old student.

The 2nd Artificial Muscles Armwrestling Contest was held on February 27, 2006. Rather than wrestling with a human opponent, this contest consisted of measuring the arms performance and comparing the results. The measuring fixture was developed jointly by individuals from UCLA and the author's group at JPL. The fixture was strapped to the contest table and the EAP actuated arms were tested for speed and pulling force. The competing arm pulled on the fixture cable that has a force gauge on its other end. To simulate a wrestling action a 0.5-kg weight was mounted on the pulling cable and had to be lifted to the top of the fixture. The time to reach the top was measured to determine the wrestling speed. As a performance baseline, the capability of the female student, who was the human wrestler in 2005, was measured first and then the three participating robotic arms were tested. The student's performance was two orders of magnitude stronger and faster. 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.

5. Summary and outlook

Technologies that allow developing biologically inspired system and, in particularly, humanlike robots are increasingly emerging. Making such robots that are actuated by artificial muscles and controlled by artificial intelligence would create a new reality with great potentials to NDE. On the very small scale, one may envision robots being used to inspect hard to reach areas of aircraft fuselage or engines where the creatures can be launched to conduct the inspection procedures and download the data upon exiting the structure. The emergence of electroactive polymers has enabled potential capabilities that are currently considered science fiction. Using effective EAP actuators to mimic nature would immensely expand the collection and 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.

As the technology progresses, 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 humanlike robots, unless intentionally designed to be fanciful. The author's armwrestling challenge having a match between EAP-actuated robots and a human opponent highlights the potential of this technology. Progress towards winning this armwrestling challenge will lead to exciting new generations of robots and is expected to benefit NDE in many forms including the development of artificial inspectors.

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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