Robotics and nature, from primitive creatures to human intelligence

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ABSTRACT
For thousands of years, humans have looked to nature to find solutions for their problems. This trend has affected the robotics field as well as artificial intelligence, manufacturing, biomechanics, vision and many others. In the robotics field, there are many unsolved problems which amazingly have been solved in nature. These problems vary from basic motion control to high level intelligence problems. Insects' motion, human's walking, driving, exploring an unstructured environment, and object recognition are examples of these problems. Robotics researchers have looked to nature to find solutions to these problems. However, what is missing is human-like computation ability. The presumption is that if we want to create a human like robot, we should implement systems which perceive and operate similar to humans. This paper is a survey on how robotics has been inspired by mimicking nature. It introduces different trends and reviews the modern biologically inspired technology. It also focuses on human perception and potentials for perception based robotics. The significance of this work is that it provides an understanding of the importance of perception in the design of a robot controller.

Keywords: Humanoid robotics, biologically inspired robotics, perception-based control

1. BACKGROUND

It seems that humans and robots are going to get along with each other in a context that is mixture of science and fiction. Scientists, predictors, and entertainers have similar dreams about future robots; however they may choose different paths to realize them. Probably what is fascinating is the social aspect of this technology. This is not necessarily about comfort, physical needs, or economical advantages. Humans are looking for companionship. Something they have always looked at nature to find. This paper will describe a survey of biologically inspired and humanoid robotics. It will cover social aspect of robotics as well as some state of the art products. In addition, methodological challenges of humanoid robots will be discussed.

The term *robot* was coined in a 1923 play by the Capek Brothers, entitled *RUR* (Rossum's Universal Robots), as a derivative of the Czech *robota* which means "forced labor".[1] The word *robotics* was coined by the renowned science fiction writer, Isacc Asimov, in the 1942 story, "Runabout."[2] Since then robotics has been inspired in many ways and has created some fears as well. Sci-fi is one of the areas which have stimulated creative activity in robotics.

The laws of robotics are an attempt to counteract some fears by building safeguards into such machines. Isaac Asimov is generally credited with creating these laws and writing a series of short stories (collected in *I, Robot*) about the application of the laws. Nevertheless, Asimov published two robot stories--"Robbie" and "Reason"--which introduced positronic brained robots and alluded to restrictions on robot behavior to counter the Frankenstein motif started by Mary Shelly.

The three original laws were first propounded *in toto* in "Runabout" (1942). These laws are so ingrained in the conventions of science fiction that most authors routinely refer to the laws or explain why they are not in effect. The Three [Original] Laws of Robotics:

First law: A robot may not injure a human being, or, through inaction, allow a human being to come to harm.
Second law: A robot must obey the orders given it by human beings except where such orders conflict with the first law.
Third law: A robot must protect its existence as long as such protection does not conflict with the first or second law.
Asimov added a fourth, or Zeroth, Law in *Robots and Empire* (1985):
Zeroth law: A robot may not injure humanity or, through inaction, allow humanity to come to harm.
First law, revised: A robot may not injure a human being or, through inaction, allow a human being to come to harm.

Today, humanoid robotics labs across the globe are working on creating a new set of robots that take us one step closer to the androids of science fiction. Building a humanlike robot is a difficult engineering task that requires a combination of mechanical engineering, electrical engineering, computer architecture, real-time control, and software engineering.[1] Human-like service robots, which can work interactively with humans in the same environment by using their natural communication means, is one of the biggest challenges for future intelligent machines.[3]

In Section 2, biologically inspired robots are reviewed. Section 3 focuses on perception based robots. Conclusions and recommendations are given in Section 4.

2. HUMANOID ROBOTS

The usual goal of robotics researchers is to understand how to design and build machines able to accomplish some tasks in the production of final products or services. In personal robotics, instead, the researcher is directly developing the final product; thus, new factors typical of product engineering design processes (such as task analysis, marketing, industrial design, reliability, and safety) must be included in the design phase. Whereas the performance of industrial robots can be measured by means of objective parameters, the success of a personal robot should be evaluated by applying subjective, user-based criteria.[4]

Biologically inspired designs are based on theories drawn from natural and social sciences, including anthropology, cognitive science, developmental psychology, ethology, sociology, structure of interaction, and theory of mind. Generally speaking, these theories are used to guide the design of robot cognitive, behavioral, motivational (drives and emotions), motor and perceptual systems. Two primary arguments are made for drawing inspiration from biological systems. First, numerous researchers contend that nature is the best model for “life-like” activity. The hypothesis is that in order for a robot to be understandable by humans, it must have a naturalistic embodiment, it must interact with its environment in the same way living creatures do, and it must perceive the same things that humans find to be salient and relevant.[5] The second rationale for biological inspiration is that it allows us to directly examine, test and refine those scientific theories upon which the design is based.[1] This is particularly true with humanoid robots.[6]

Adams et al. hope not only to produce robots that are inspired by biological capabilities, but also to help shape and refine our understanding of those capabilities. By bringing a theory to bear on a real system, the proposed hypotheses are tested in the real world and can be more easily judged on their content and coverage.[1]

2.1 Social complexity and evolution theory

Humans and animals have faced similar physical challenges during evolution. If our needs were only about physical needs and survival, we would not need the brain and intelligence that we already have. It seems social complexity was the great challenge which required this huge brain in comparison to other mammals. Brain size alone is not the key difference since elephants have much larger brains than humans. However, the use of perception and natural language must be a major factor in human intelligence. This shows the magnitude of the problem that designers of humanoid robots are facing. While our current technology is not comparable even with low level creature’s abilities, humanoid robotics is facing the social complexity of human as well as its physical skills problem. Some companies already claim that their products are true companions and they should be treated similar to a pet.

2.2 Social robots

Many species of mammals (including humans, birds, and other animals) often form individualized societies. Individualized societies differ from anonymous societies because the individual matters. Although individuals may live in groups, they form relationships and social networks, they create alliances, and they often adhere to societal norms and conventions.[7]

Dautenhahn and Billard proposed the following definition: “Social robots are embodied agents that are part of a eterogeneous group: a society of robots or humans. They are able to recognize each other and engage in social interactions, they possess histories (perceive and interpret the world in terms of their own experience), and they explicitly communicate with and learn from each other.”[8]

In particular, social learning and imitation, gesture and natural language communication, emotion, and recognition of interaction partners are all important factors. Moreover, most research in this area has focused on the application of “benign” social behavior. Thus, social robots are usually designed as assistants, companions, or pets, in addition to the more traditional role of servants.[6]

“Socially interactive robots” has been used to describe robots for which social interaction plays a key role. This is important to distinguish these robots from other robots that involve “conventional” human–robot interaction, such as those used in teleoperation scenarios. The focus is on peer-to-peer human–robot interaction. Specifically, robots that exhibit the following “human social” characteristics:

- Express and/or perceive emotions;
- Communicate with high-level dialogue;
- Learn/recognize models of other agents;
- Establish/maintain social relationships;
- Use natural cues (gaze, gestures, etc.);
- Exhibit distinctive personality and character;
- May learn/develop social competencies.[6]

Socially interactive robots can be used for a variety of purposes: as research platforms, as toys, as educational tools, or as therapeutic aids. The common, underlying assumption is that *humans prefer to interact with machines in the same way that they interact with other people*.[6]

2.3 Some biologically inspired robots

Cog (Figure 1) began as a 14 degree-of-freedom upper torso with one arm and a rudimentary visual system. In this first incarnation, multimodal behavior systems, such as reaching for a visual target, were implemented. Currently, Cog features two six degree-of-freedom arms, a seven degree-of-freedom head, three torso joints, and a much richer array of sensors. Each eye has one camera with a narrow field-of-view for high resolution vision and one with a wide field-of-view for peripheral vision, giving the robot a binocular, variable-resolution view of its environment.

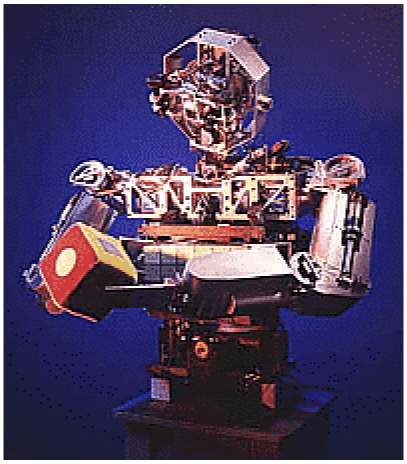

Figure 1. MIT humanoid robot, Cog, has twenty-two degrees of freedom

Following the success of Sony Corporation's 'AIBO,' robot cats and dogs are multiplying rapidly. AIBO means "companion" in Japanese. It is also an acronym for Artificial Intelligence roBOt.

"Robot pets" employing sophisticated artificial intelligence and animatronic technologies are now being marketed as toys and companions by a number of large consumer electronics corporations.[9]

A legged robot application developed by MIT Leg Laboratory is shown in Figure 2. Troody is an 11-pound walking birdlike robotic dinosaur which is being marketed to natural history museums for educational and entertainment purposes.

Figure 2. Troody the dinosaur robot of MIT

Figure 3. AIBO from Sony

The "Sprawl" family of hand-sized hexapedal robots are prototypes designed to test ideas about locomotion dynamics, leg design and leg arrangement and to identify areas that can be improved by Shape Deposition Manufacturing. Sprawlita is a dynamically-stable running hexapod based on functional principles from biomechanical studies of the cockroach. The prototype was fabricated using Shape Deposition Manufacturing and is capable of speeds of approximately 3 body-lengths per second.[10]

Honda engineers created ASIMO with 26 Degrees of Freedom that help it walk and perform tasks much like a human. One degree of freedom is the ability to move right and left or up and down. At birth the human body has about 350 bones, but by the time adulthood rolls around, some of our bones have fused together to give us a total of 206 bones in our body.

If each of these bones is considered as a link that moves with a single degree of freedom then over 200 degrees of freedom are needed to emulate human motion. These degrees of freedom act much like human joints for optimum movement and flexibility. According to Honda, ASIMO stands for "Advanced Step in Innovative Mobility." It probably derives also from the late Isaac Asimov who wrote "I, Robot" in 1950 and announced the three laws of robotics.

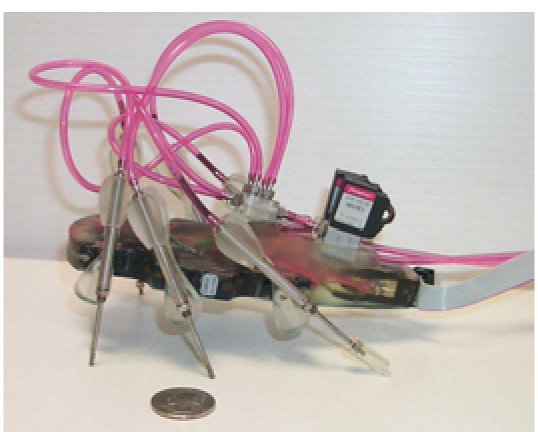

Figure 4. Sprawlita from Stanford's Biomimetic Robotics Lab

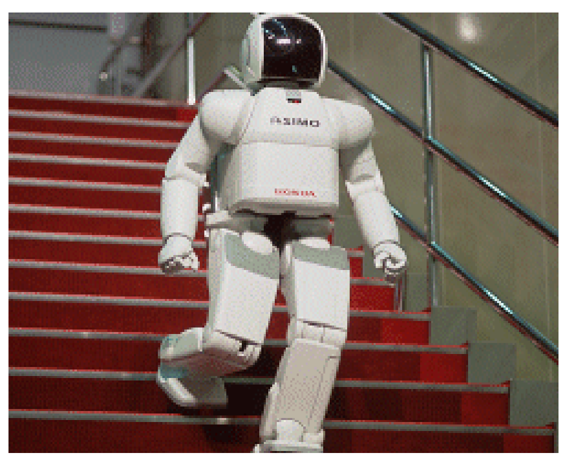

Figure 5. ASIMO from Honda

The Hasbro / Wow-wee B.I.O. Bugs are a series of battery-powered autonomous / remote-controlled robot bugs. They are substantial beasts, measuring 25cm x 29cm (9.8" x 11.4") excluding sensors and weighing 0.492kg (1.08lbs) in the case of the Predator bug. The name B.I.O.-Bugs stands for biomechanical integrated organisms. The basic capabilities of these 2 motor walkers is considerable: they can traverse surfaces as deep as shag carpeting (on full batteries) with little problem. They can perform a fairly sharp turn, within 1.5x their body length, which is a fairly impressive feat using only 2 motors. They broadcast and receive IR data via the forehead / butt ports, and can recognize friend, foe, and IR controller input. An additional transmitter is located on the rear of the robot, leaving a blind spot only when the remote is aimed at the mid-riff from an angle of about 110 degrees from the angle of travel.

According to NASA website Robonaut is a humanoid robot designed by the Robot Systems Technology Branch at NASA's Johnson Space Center in a collaborative effort with DARPA. The Robonaut project seeks to develop and demonstrate a robotic system that can function as an EVA (extra-vehicular activity) astronaut equivalent. Robonaut jumps generations ahead by eliminating the robotic scars (e.g., special robotic grapples and targets) and specialized robotic tools of traditional on-orbit robotics. However, it still keeps the human operator in the control loop through its telepresence control system. Robonaut is designed to be used for "EVA" tasks, i.e., those which were not specifically designed for robots.

Figure 6. BIO bug from Wow-wee toy maker

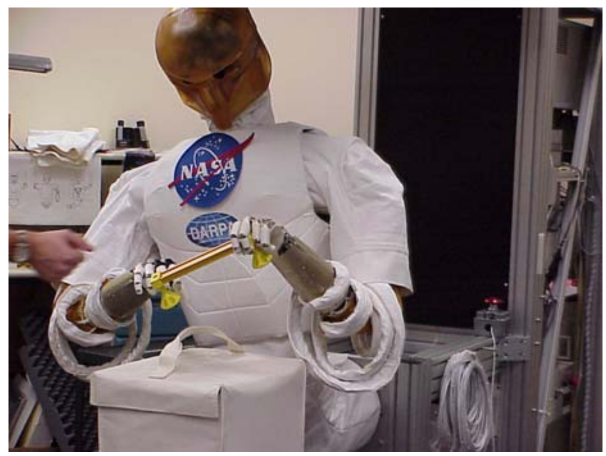

Figure 7. Robonaut, a humanoid robot from NASA

3. PERCEPTION-BASED ROBOTICS

Natural, effortless communication between robots and humans has not yet been realized. There are two reasons for this. The first is that these kinds of social robots are considered to exist only for accurately executing instructions assigned by humans, like industrial robots. With this approach, natural communication like that carried out between humans is not implemented. Kanda et al. believe that to implement social robots, bidirectional communication between equals must be implemented, not a master–servant relationship in which one side gives instructions to the other. The second reason is that the “principle of individual capabilities” has been followed, which attempts to implement “intelligence” similar to that of humans by using only computational mechanisms within the robot. However, even humans do not actually calculate everything within their heads. Instead, we should consider that “intelligence” is produced from interactions with the surrounding environment.[9]

An example of such problem is RoboCup. According to its website: “RoboCup is an international joint project to promote AI, robotics, and related fields. It is an attempt to foster AI and intelligent robotics research by providing a standard problem where wide range of technologies can be integrated and examined. RoboCup chose to use soccer game as a central topic of research, aiming at innovations to be applied for socially significant problems and industries. The ultimate goal of the RoboCup project is By 2050, develop a team of fully autonomous humanoid robots that can win against the human world champion team in soccer. In order for a robot team to actually perform a soccer game, various technologies must be incorporated including: design principles of autonomous agents, multi-agent collaboration, strategy acquisition, real-time reasoning, robotics, and sensor-fusion. RoboCup is a task for a team of multiple fast-moving robots under a dynamic environment."* Ad Hoc communication networks and the Bluetooth standard is an interesting technology for such communication need.

To interact meaningfully with humans, social robots must be able to perceive the world as humans do, i.e., sensing and interpreting the same phenomena that humans observe. This means that, in addition to the perception required for conventional functions (localization, navigation, obstacle avoidance), social robots must possess perceptual abilities similar to humans.

In particular, social robots need perception that is human-oriented: optimized for interacting with humans and on a human level. They need to be able to track human features (faces, bodies, hands). They also need to be capable of interpreting human speech including affective speech, discrete commands, and natural language. Finally, they often must have the capacity to recognize facial expressions, gestures, and human activity. Similarity of perception requires more than similarity of sensors. It is also important that humans and robots find the same types of stimuli salient.[6, 11] Moreover, robot perception may need to mimic the way human perception works. For example, the human ocular-motor system is based on foveate vision, uses saccadic eye movements, and exhibits specific visual behaviors (e.g., glancing). Thus, to be readily understood, a robot may need to have similar visual motor control.[6, 12, 13]

In the case of navigation when the robot visits a certain area several times, the obtained information can be used to improve the quality of the navigation. However, in many real world applications it is not possible to have previous data about the course and predict the dynamic environment. One example is driving a car in a city. That is a place that human perception shows its extra ordinary capability.

The classical AI methodology has two important assumptions: the ability to represent hierarchical structure by abstraction, and the use of "strong" knowledge that utilizes explicit representational assertions about the world.[14] The assumption was that knowledge and knowledge representation are central to intelligence, and that robotics was no exception. Perhaps these were the result of studying human-level intelligence and not lower live forms of creatures. Behavior-based robotics systems reacted against these traditions.[15]

Behavior-based control shows potentialities for the robot-navigation environment since it does not need the building of an exact world model and a complex reasoning process.[16] However, much effort should be made to solve aspects like formulation of behaviors and the efficient coordination of conflicts and competition among multiple behaviors. In order to overcome these deficiencies, some fuzzy-logic-based behavior control schemes have been proposed.[17]

Behavior-based control is an effective method for designing low-level primitives that can cope with real-world uncertainties, and AI has developed effective tools for symbol manipulation and reasoning.[18] Integration of these two could result a better understanding and modeling of human perception. The collection of these methods now is called soft computing.

Perception is the name given for the process of the organization, interpretation and the explanation of the data reaches to the brain from the sense organs. The data reaching at the sense organs have no importance without perception. The senses have to be perceived, in other words explained. We can only decide what kind of a reaction we are going to give to the senses only after perception.

Perception is a vital part of human reasoning. Human do a variety of physical and mental tasks without any measurements and computations. Some examples of these activities are driving in traffic, parking a car, cooking a meal, playing an instrument and summarizing a story. In fact, the capability to perform these tasks is based on the brain's ability to manipulate perceptions, perceptions of time, distance, force, direction, speed, shape, color, likelihood, intent, truth and other attributes of physical and mental objects.[19]

The literature on perception is huge, including thousands of papers and books in the areas of psychology, linguistics, philosophy, brain science, and many others.[20] *And yet, what is not in existence is a theory in which perceptions are treated as objects of computation*. Such a theory is needed to make it possible to conceive, design, and construct systems which have much higher machine intelligence than those we have today. [19]

* http://www.robocup.org

The difficulty of talking to robots comes from both sides of the communication channel. The first problem is that it is human dependent. Different people use natural language in a variety of ways and sometimes it is vague. The second problem is the limitations of robots to interact with their environments. This depends on the quality of the perception system. Limitation of this system should also be taken into consideration at the natural language interface design stage. The discrepancy between the human perception system and the perception of robots is one of the foreseeable sources of communication problems. [21]

Most of research on verbal communication with robots has mainly focused on issuing commands, like activating pre-programmed procedures using a limited vocabulary.[18] They directly convert the voice commands to measurement without computing on perceptions.

Information which is conveyed by propositions drawn from a natural language will be said to be perception-based.[22] Natural language perception-based control (NLPC) can be defined as "*perceiving information about the dynamic environment by interpreting the natural language and reacting accordingly*".

In the NLPC, perceptions are not dealt with directly. Instead, NLPC deals with the descriptions of perceptions expressed in the natural language. Therefore, propositions in a natural language play the role of surrogates of perceptions. In this way, manipulation of perceptions is reduced to a familiar process, manipulation of propositions expressed in a natural language.[19]

Perceptions are fuzzy in the sense that perceived values of variables are not sharply defined and perceptions are granular in the sense that perceived values of variables are grouped into granules, with a granule being a clump of points drawn together by indistinguishability, similarity, proximity or functionality. For example, the fuzzy granules of the variable Age might be young, middle-aged and old (Fig. 7) [22].

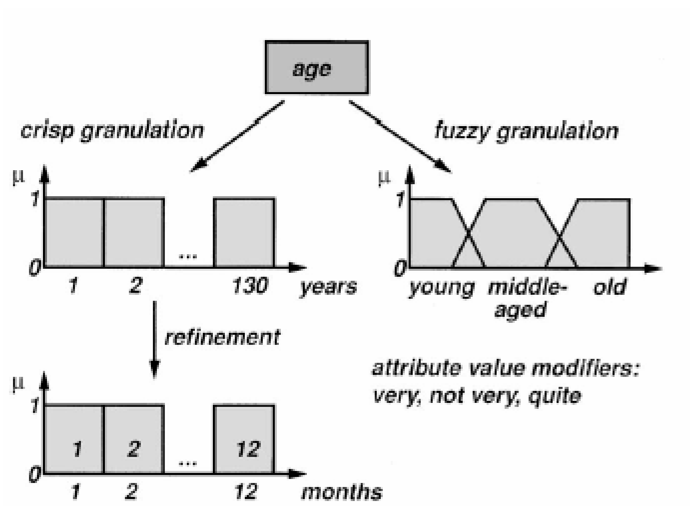

Figure 7. Crisp and fuzzy granulation of Age (from Zadeh [22])

Therefore, fuzzy logic theory will be used as a departing point for computing on propositions and perception-based robot control. This will be done through the use of what is called constraint-centered semantics of natural languages (CSNL) [19, 22, 23].

The principal ideas and assumptions which underlie CSNL may be summarized as follows:

- Perceptions are described by propositions drawn from a natural language.
- A proposition, *p*, may be viewed as an answer to a question.
- A proposition is a carrier of information.
- The meaning of a proposition, p, is represented as a generalized constraint which defines the information conveyed by *p*.
- Meaning-representation is viewed as translation from a language into the generalized constraint language

More needs to be done to develop a computational theory of perceptions applicable to the robot control.

4. CONCLUSION

Nature is a source of inspiration for human kind. People have adopted many solutions from nature and continue to do. Humanoid robots are among the greatest challenges to overcome since this time human is trying to create a nature like companion for its complex social needs and not necessarily the physical needs. In recent years interesting researches have been done to imitate the human physics and behavior. However, what is missing is human-like computation ability. The presumption is that if we want to create a human like robot, we should implement systems which perceive and operate similar to human. Perception-based robot control – driven from computational theory of perceptions- is an immature but encouraging direction toward robot control. The main idea of this theory is that perceptions should be objects of computation instead of converting them to measurements, when it is necessary and useful.

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