Humanoid Robots: Historical Perspective, Overview, and Scope

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Abstract

This article provides an overview of humanoid robotics. The historical perspective of the field is framed within the development of robotics throughout the last 65 years or so. A brief discussion of the main challenges and their scopes is provided, along with the research trends and their societal implications.

1 A Brief History of Robotics

The dream to create machines that are skilled and intelligent has been part of humanity from the beginning of time. This dream is now becoming part of our world's striking reality. Since the early civilizations, one of human's greatest ambitions has been to create artifacts in their image. The legend of the Titan Prometheus, who molded humankind from clay, or that of the giant Talus, the bronze slave forged by Hephaestus (3500 BC), testify to this quest in Greek mythology. The Egyptians' oracle statues hiding priests inside (2500 BC) were perhaps the

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precursor of our modern thinking machines. The clepsydra water clock introduced by the Babylonians (1400 BC) was one of the first automated mechanical artifacts. In the following centuries, human creativity has given rise to a host of devices such as the automaton theatre of Hero of Alexandria (100 AD), the hydro-powered water-raising and humanoid machines of Al-Jazari (1200), and Leonardo da Vinci's numerous ingenious designs (1500). The development of automata continued to flourish in the eighteenth century both in Europe and Asia, with creations such as Jacquet-Droz's family of androids (drawer, musician, and writer) and the "karakuri-ningyo" mechanical dolls (tea server and archer).

The robot "concept" was clearly established by those many creative historical realizations. Nonetheless, the emergence of the "physical" robot had to await the advent of its underlying technologies during the course of the twentieth century. In 1920, the term robot – derived from "robota" which means subordinate labor in Slav languages – was first introduced by the Czech playwright Karel Čapek in his play "Rossum's Universal Robots (R.U.R.)." In 1940, the ethics of the interaction between robots and humans was envisioned to be governed by the well-known three fundamental laws of Isaac Asimov, the Russian science-fiction writer in his novel "Runaround."

The middle of the twentieth century brought the first explorations of the connection between human intelligence and machines, marking the beginning of an era of fertile research in the field of artificial intelligence (AI). Around that time, the first robots were realized. They benefited from advances in the different technologies of mechanics, controls, computers, and electronics. As always, new designs motivate new research and discoveries, which, in turn, lead to enhanced solutions and thus to novel concepts. This virtuous circle over time produced that knowledge and understanding which gave birth to the field of *robotics*, properly referred to as the science and technology of robots.

The early robots built in the 1960s stemmed from the confluence of two technologies: numerical control machines for precise manufacturing and teleoperators for remote radioactive material handling. These master-slave arms were designed to duplicate one-to-one the mechanics of the human arm and had rudimental control and little perception about the environment. Then, during the mid-to-late twentieth century, the development of integrated circuits, digital computers, and miniaturized components enabled computer-controlled robots to be designed and programmed. These robots, termed industrial robots, became essential components in the automation of flexible manufacturing systems in the late 1970s. Further to their wide application in the automotive industry, industrial robots were successfully employed in general industry, such as the metal products, the chemical, the electronics, and the food industries. More recently, robots have found new applications outside the factories, in areas such as cleaning, search and rescue, underwater, space, and medical applications.

In the 1980s, robotics was defined as the science that studies the intelligent connection between perception and action. With reference to this definition, the action of a robotic system is entrusted to a locomotion apparatus to move in the environment (wheels, crawlers, legs, propellers) and/or to a manipulation apparatus to operate on objects present in the environment (arms, end effectors, artificial hands), where suitable actuators animate the mechanical components of the robot. The perception is extracted from the sensors providing information on the state of the robot (position and speed) and its surrounding environment (force and tactile, range and vision). The intelligent connection is entrusted to a programming, planning, and control architecture, which relies on the perception and available models of the robot and environment and exploits learning and skill acquisition.

In the 1990s, research was boosted by the need to resort to robots to substitute for human physical presence in challenging environments (field robotics) or by the desire to develop products with wide potential markets aimed at improving the quality of life (service robotics). A common denominator of such application scenarios was the need to operate in a scarcely structured environment, which ultimately requires increased abilities and a higher degree of autonomy.

The video "Robots — A 50 Year Journey" by Oussama Khatib (2000) https://vimeo.com/137042620 shows the development of robotics through the first five decades.

By the dawn of the new millennium, robotics has undergone a major transformation in scope and dimensions. This expansion has been brought about by the maturity of the field and the advances in its related technologies. From a largely dominant industrial focus, robotics has been rapidly expanding into the challenges of the human world (human-centered and life-like robotics). The new generation of robots is expected to safely and dependably cohabitat with humans in homes, workplaces, and communities, providing support in services, entertainment, education, healthcare, manufacturing, and assistance.

Beyond its impact on physical robots, the body of knowledge robotics has produced is revealing a much wider range of applications reaching across diverse research areas and scientific disciplines, such as biomechanics, haptics, neurosciences, virtual simulation, animation, surgery, and sensor networks, among others. In return, the challenges of the new emerging areas are proving an abundant source of stimulation and insights for the field of robotics. It is indeed at the intersection of disciplines that the most striking advances are expected to happen.

The video "Robots — The Journey Continues" by Bruno Siciliano, Oussama Khatib, and Torsten Kröger (2016) https://vimeo.com/173394878 shows the intensive and vibrating evolution of robotics through the last fifteen years.

2 Humanoid Robots

The long saga of humanoid robots in science fiction has influenced generations of researchers, as well as the general public, and serves as evidence that people are drawn to the idea of humanoid robots. Humans generally like to observe and interact with one another. In their social behavior, people are highly attuned to human characteristics, such as the sound of human voices and the appearance of human faces and body motion. Infants show preferences for these types of stimuli at a young age, and adults appear to use specialized mental resources when interpreting these stimuli. By mimicking human characteristics, humanoid robots can engage these same preferences and mental resources.

Throughout history, the human body and mind have inspired artists, engineers, and scientists, using media as diverse as cave paintings, sculpture, mechanical toys, photographs, and computer animation. Humanoid robots serve as a powerful new medium that enables the creation of artifacts that operate within the real world and exhibit both human form and behavior. The field of humanoid robotics focuses on the creation of robots that are directly inspired by human capabilities and/or selectively imitate aspects of human form and behavior. Humanoids come in a variety of shapes and sizes, from complete human-size legged robots to isolated robotic heads with human-like sensing and expression.

The motivations that have driven the development of humanoid robots vary widely. Humanoid robots have been developed to serve as general-purpose mechanical workers, entertainers, and test-beds for theories from neuroscience and experimental psychology. On a daily basis, humans perform important tasks that are well beyond the capabilities of current robots. Moreover, humans are generalists with the ability to perform a wide variety of distinct tasks. Roboticists would like to create robots with comparable versatility and skill. Considering the physical and computational mechanisms that enable a person to perform a task is a common approach to automating it. Exactly what to borrow from the human example is controversial. The literal-minded approach of creating humanoid robots may not be the best way to achieve some human-like capabilities. For example, dishwashing machines bear little similarity to the manual dishwashing they replace.

People inhabit environments that accommodate human form and human behavior. Many important everyday objects fit in a person's hand and are light enough to be transported conveniently by a person. Human tools match human dexterity. Doors tend to be a convenient size for people to walk through. Tables and desks are at a height that is well matched to the human body and senses. Humanoid robots can potentially take advantage of these same accommodations, thereby simplifying tasks and avoiding the need to alter the environment for the robot. Humanoid robots can also interface with machinery that does not include drive-by-wire controls, as, e.g., by a teleoperated robot in the cockpit of a backhoe.

Robots with legs and human-like behavior are at the heart of some of the most exciting work in modern robotics. They offer the opportunity to travel to places beyond the reach of wheeled systems and gain fundamental insights into the conditions under which stable and efficient locomotion is possible. For example, legs could enable a humanoid robot to change its posture in order to lean into something, pull with the weight of its body, or crawl under an obstacle. At the same time, their complex dynamics pose significant challenges for our computational approaches to control and stability analysis.

Humanoid robots are conceived to work with humans in their daily environment. For example, humanoid robots and humans could potentially collaborate with one another in the same space using the same tools. When the robot moves in our environment, safety is one of the most challenging problems. In the actual environment, multiple contact and unpredictable contact happen between the robot and the environment or between the robot and human. If these interactions are not fully considered in robot control, they may cause instability of balance and task failures. From this point of view, compliant and robust contact and motion control is crtitical for humanoid robots.

Besides the physical interaction, cognitive human–robot interaction is a major research area. Humanoid robots can potentially take advantage of the communication channels that already exist between people. A challenge for humanoid robots is to convey and interpret human intent through subtle natural movements and gestures such as eye gaze, facial expressions, and body language. As robots begin to appear more humanlike, people might experience an unsettling feeling. This is the so-called "uncanny valley" concept, according to which the positive relationship between a robot's degree of human likeness and our affinity for it continues to grow until a point when it sharply turns negative. This phenomenon constitutes another important aspect toward future design and development of human-friendly humanoid robots.

Humanoid robots can be used to assist and communicate with us in our homes, offices, public spaces, hospitals, and disaster areas. The introduction and deployment of humanoid robots has a number of significant implications on our society ranging from economy to the working force and robot safety and dependability. The ethical, legal, and societal (ELS) issues raised in the last fifteen years within Artificial Intelligence and Robotics have increasingly gained importance with the development of humanoid robots and their interaction with humans. These issues will need to be carefully addressed before coexistence between humanoid robots and humans can be achieved.

On the other hand, many researchers in the humanoid robotics community see humanoid robots as a tool with which to better understand humans. Humanoid robots offer an avenue to test understanding through construction (synthesis), and thereby complement the analysis provided by researchers in disciplines such as biomechanics and cognitive science.

The synthesis of human motion is a complex procedure that involves accurate reconstruction of movement sequences, modeling of musculoskeletal kinematics, dynamics and actuation, and characterization of reliable performance criteria. Accurate modeling and detailed understanding of human motion will have a significant impact on a host of domains: from the rehabilitation of patients with physical impairments to the training of athletes or the design of machines for physical therapy and sport.

The well-known haptics concept in robotics can also be keenly combined with functional magnetic resonance imaging to enable complex motor neuroimaging experiments that study how day-to-day manipulation tasks map on to the brain. A haptic interface simulates physical interaction by applying appropriate forces whenever humans touch and feel virtual objects.

Researchers have sought to better imitate human intelligence using humanoid robotics. Developmental psychologists, linguists, and others have found strong links between the human body and human cognition. By being embodied in a manner similar to humans, and situated within human environments, humanoid robots may be able to exploit similar mechanisms for artificial intelligence. Researchers are also attempting to find methods that will enable robots to develop autonomously in a manner akin to human infants.

In addition to the above research aspects, humanoid robots could play roles in entertainment and education. Realism in form and function could make humanoid robots preferable to wax figures and animatronics. A humanoid robot could serve as an avatar for telepresence, model clothing, test ergonomics, or serve other surrogate roles that fundamentally depend on the robot's similarity to a human. Robotic prostheses and cosmoses also have a close relationship to humanoid robotics, since they seek to directly replace parts of the human body in function and form.

As widely discussed in this reference book, humanoid robotics is an enormous research and development endeavor. The emulation of human-level abilities in a human-like robot serves as a grand challenge for robotics, with significant cultural ramifications going much beyond the boundaries of engineering and technology. Besides this deep societal motivation, humanoid robots offer unique opportunities for human–robot interaction, and integration into human-centric settings. Over the past decade, the number of humanoid robots developed for research has grown significantly, as has the research community. Humanoid robots have already gained a foothold in the marketplace as robots for entertainment and research. Given the special properties of humanoid robots, they seem likely to further increase in number as their capabilities improve and their cost may become affordable. Robots with human characteristics, and technologies related to humanoid robotics, also appear destined to proliferate. Will human-scale, legged robots with human form become commonplace, as so often imagined by science fiction? Only time will tell.