

HUMANOIDS

Humanoid robotics—History, current state of the art, and challenges

We have always been fascinated by what it means to be human; the theme has been extensively explored in the sciences as well as the arts (such as literature and film). *Rossum's Universal Robots* (by Czech writer Karel Čapek in the 1920s) introduced the word “robot” to describe creatures that look human but used only for tedious labor. The work has had an extensive influence on modern societies, inspiring the development of machines (humanoids) that not only resemble humans but also are intelligent and can act, reason, and interact like human beings. This ultimate dream has led to many robotic embodiments in recognizably anthropomorphic forms integrating motion, perception, and interaction to recreate the physical, cognitive, and social functions of humans.

Humanoid robotics is an important branch of biometric robotics and is not only associated with science and engineering disciplines but also deeply connected to social, legal, and ethical domains. Early attempts significantly underestimated the challenges associated; nevertheless, new theory and technologies have now come to fruition in realizing humanoid robots beside the classic Automata and Karakuri robots.

One important contribution to humanoid robotics was the zero-moment point (ZMP) stability theory introduced by Miomir Vukobratović in the 1960s. The first humanoid statically and later dynamically balanced robot, WABOT, by Ichiro Kato of Waseda University, Japan, was developed around the same time. For such achievements, these scientists must be recognized as pioneers of humanoid robotics. Since then, many scientists and engineers have been working on this topic. In 1997, Honda Motor revealed the Humanoid P2 at the 1997 IEEE International Conference on Intelligent Robots and Systems (IROS) in Grenoble, France. Subsequent development led to the ASIMO robot announced in 2000. The impact was felt beyond the robotics community: The general public was excited by its human-like android shape, natural gait walk, automatic slope balance, ability to climb up and down stairways, and human interactions. An increasing number of researchers have since been challenged to further develop humanoid robots.

After the Fukushima nuclear power plant disaster, the 2015 Defense Advanced Research Projects Agency (DARPA) Robotics Challenge demonstrated marked progresses in many ongoing humanoid projects. However, they still fell below our expectations (1). The humanoid robot clearly needs more research and development not only in me-

chanical design and control but also in perception and recognition capabilities. We are, after all, still at the beginning of a long journey of creating a humanoid robot that is intelligent and can act, reason, and interact like a human being in real-world scenarios.

While facing the challenges of designing and building a humanoid robot, it is important to provide extensive sensorimotor capabilities and to promote the discovery of new techniques and methods, which can be applied to more task-specific service robots or in other engineering fields. In the quest for humanoid robots, some laudable achievements include robots and machines with biped locomotion (2), learning capabilities (1), neuro-inspired control (1), predictive architectures (1), and many more bioinspired functions, making robots more effective in real-life settings.

Furthermore, humanoid robots can represent a research platform for studying not only robotics but also human beings. This is especially true for neuroscience, where human brain models can be implemented on humanoid robots. This can allow testing and validation of these models, in addition to providing humanoids with human-like sensorimotor functions. In fact, Mitsuo Kawato of ATR Japan proposed using humanoid robots to study human behavior at the beginning of this century (3). In Europe, this approach has been pursued in a number of EU-funded projects, which include the large-scale NEUROBOTICS project (4) across neuroscience and robotics and the RobotCub project, which led to the open iCub platform for the study of the development of cognitive capabilities (5). Today, the Human Brain Project consists of a dedicated neurorobotics platform for the implementation of brain models (6).

We applaud the agility of the Atlas humanoid robot by Boston Dynamics in doing backflips and the wisdom of the robot Sophia in engaging in conversations, but what are the challenges ahead for humanoid robotics? Clearly, there remain many outstanding research issues in bipedal locomotion and dexterous manipulation for complex environments, perception, human-robot interaction, and collaboration in real-world scenarios, as well as understanding intention, learning behavior, and sensing emotion. Despite the initial implementation of a variety of brain models for specific sensorimotor behaviors, the integration of a “robot brain”—with several functions, adequate decisional mechanisms, and appropriate simplicity principles—represents an interesting challenge. For the body, we need to rethink the materials that robots are



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