A Survey on Humanoids Robots: Perception, Mechanism, and Control

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Anthropomorphic robots, also known as humanoids, have a structure based on the human body, with limbs and movements designed for better mobility that allows the robot to perform various tasks, mainly to assist people in daily activities, for entertainment, or to perform risky tasks. The development of this document aims to present some of the results obtained in the research conducted on the state-of-the-art study about humanoid robots based on some of the main articles related to their study, highlighting some of their characteristics of perception systems, control, and physical configurations.
Keywords: Anthropomorphic Robots. Humanoids. Biped Locomotion.

Introduction

Anthropomorphic robots, also known as humanoids, possess attributes similar to the human form, such as heads, arms, and legs. They can therefore be bipedal, allowing them to maneuver in uneven terrain. These characteristics are essential since more than 50% of the earth's surface is inaccessible to traditional wheeled vehicles [1]. In addition, they offer other advantages, such as turning around their own body by rotating their feet and having free hands for manipulation, fundamental for interaction with objects designed to be used by humans, such as door handles, switches, levers, valves, and work tools [2].

According to Verified Market Research [3], the global humanoid robots market is expected to grow by about 52.53% by 2028 over 2020, mainly due to their use for security, surveillance applications, detection of intruders and terrorist activities, in hazardous environments, in healthcare, in academic research, and to support daily tasks [3]. Thus, these robots have been applied in varied applications.

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As reported by the Royal Aeronautical Society [4], SoftBank's Pepper robot, for example, is used as an attendant at the Oakland airport in California, providing information about directions and recommendations on food and beverages. Also, this same robot model has been used in airports in Belgium and Japan and other environments such as schools, hospitals, restaurants, and stores in the United States [4].

Humanoid robots have applications to assist caregivers and patients, especially in risky areas such as contaminated environments, and thus can be used for medical and surgical uses [5]. For example, as stated by Catherine Clifford [6], the startup CloudMinds made robots available to various medical facilities to help care for patients amid the Coronavirus pandemic. Meanwhile, the humanoid robot Ginger assisted admissions to a hospital by providing information and dancing for patient entertainment [6,7].

One of the factors driving the development of hardware innovations and research related to humanoid robots is the challenges promoted by different institutions. For example, the DARPA Robotics Challenge, promoted from 2012 to 2015 by the Defense Advanced Research Projects Agency, aimed to develop robots with the ability to perform several tasks that may be needed in a disaster and rescue scenario [8]. This event generated a breakthrough in the state-of-the-art of anthropomorphic robots. It was also one of the drivers for the investment return of research in these robots in the United States.

Another challenge promoted with humanoid robots is the soccer championships, such as the RoboCup Humanoid League, an international educational and research initiative focused on advances in artificial intelligence and robotics. This program aims to develop robots capable of beating a human team by 2050, thus encouraging the development of technological innovations [9,10].

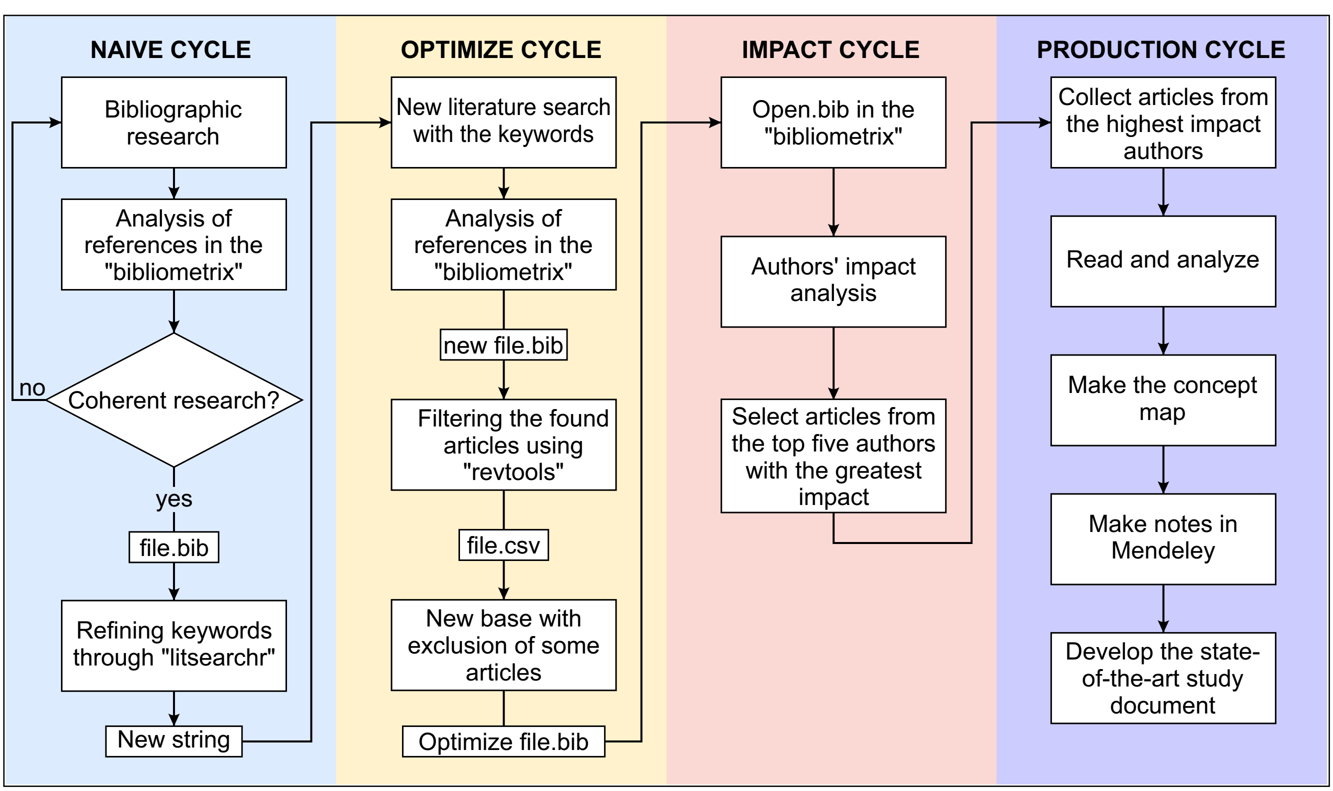
However, the high initial cost of robots and the need for a high-level infrastructure for their development and manufacturing could have prevented growth in this area. Also, they have complex mechanisms and control modes. Therefore, their performance is related to several factors, including their mechanisms, actuation, perception, and control methods [11].

Given this type of robot's great applicability and relevance, it is of utmost importance to conduct studies and research to improve the performance of humanoid robots so that they can be more widespread in everyday activities. Thus, this document presents some of the results obtained in the research on the state-of-the-art studies about humanoid robots based on main articles related to developers, focusing on the principal characteristics of perception systems, control, and physical configurations.

Materials and Methods

The BILI method (Bibliographic and Literary Review Method) was used to develop this research, which is a literature review methodology for identifying the works of authors with the most significant impact on a given research theme. This process uses data mining techniques implemented by algorithms in R based on the laws of Zipf, Lotka, and Bradford, rules arising from bibliometrics. Therefore, these packages were used: bibliometrix [12], litsearchr [13], and revtools [14]. This method comprises four phases (Figure 1) and uses tools to select, review

Figure 1. Methodology diagram.



and organize the documentation found, which is described in more detail in reference [15].

The base used to search for articles was Scopus [16], considered one of the largest databases of abstracts and citations in the literature. Then, the references were analyzed to obtain selected articles with relevant information that contributed to the research development. This analysis was carried out using biblioshiny, an interface from the bibliometrix package that allows the evaluation of references through bibliometric indicators. In the first cycle (naive) of the Bili method, 419 articles were obtained, 215 of which refer to the years between 2015 and 2021. After filtering this data in cycle 2 (optimize), 93 articles were obtained, 56 of which were published between 2015-2021, with an average annual growth of 17.08%.

The analysis by the authors used bibliometrix based on the total citations' indexer among the authors. Then, the selection of the articles was made based on their availability. So, the following articles were selected: Gait Controllers on Humanoid Robot Using Kalman Filter and PD Controller [17], Modifying the estimated ground height to mitigate error effects on bipedal robot walking and Mechanism [18], Actuation, Perception, and Control of Highly Dynamic Multilegged Robots: A Review [1] as a priority for reading. In addition, another author who was a reference for the study was Dragomir Nenchev through his contributions presented in the book Humanoid robotics: a reference [24], which was also very relevant to this research.

Results and Discussion

The section Robots Models will discuss the main characteristics of some humanoid robots used by researchers to perform studies on biped locomotion. The main characteristics of anthropomorphic robots' perception, mechanical structure, and control systems are presented in the second, third, and fourth subsections. These are significant issues in developing these robots because they influence the efficiency of their system.

<u>Robots Models</u>

NAO was developed by SoftBank Robotics and used for research and education. Among its applications is its use as an assistant in companies and health institutes. NAO is 58 cm tall, has two 2D cameras to recognize objects and people, and can communicate in several languages through its four microphones and speakers. The robot has seven touch sensors on its head, hands, feet, sonar, and an IMU to find itself in space. It has 25 degrees of freedom (DOF), allowing it to move and adapt to the environment [19].

The Darwin-OP (Dynamic Anthropomorphic Robot with an Intelligence-Open Platform) is a small humanoid (45.5 cm) developed by Robotis. It has 20 DOF and weighs 2.9 kg; it has an HD camera, gyroscope, accelerometer, and stereo microphone. Darwin can walk, talk, and dance, and it is widely used by researchers and programmers [20].

Lola is a humanoid robot developed at the Technical University of Munich (TUM) and used in research on biped locomotion dynamics and control aspects. The robot has 24 DOF, a height of 180 cm, and weighs 60 kg. Its design was developed to have low weight, high rigidity, legs with low inertia, and a high center of gravity. Regarding the sensors used by the robot, Lola has encoders on the axes of its motors and custom force/torque sensors (FTS) on its feet; it has an IMU on its torso and an Intel RealSense camera on its head [21].

HUBO 2 was developed in the HUBO lab at KAIST (Korean Advanced Institute of Science and Technology) in South Korea. It is 125 cm long, weighs 45 kg, and has 40 DOF. Its design was intended to be very light, which allowed the HUBO 2 to run at a speed of 3.6 km/h. Its perception system comprises cameras, inertia, inclination, and force/torque sensors. Its major differentiator from other bipedal robots is the ability to use a gait with outstretched legs [22].

<u>Mechanisms</u>

Humanoid robots have many DOFs to perform a human-like bipedal movement. It is recommended to consider a redundant configuration with additional DOFs to make this movement more natural and flexible [23].

To improve the dynamics of the robot legs, one should ensure sufficient mechanical stiffness, a high center of mass, and low moments of inertia of the leg links. The primary goal of a humanoid robot is to balance the structural stiffness and actuator performance with the lightness of the mechanical components. Lola's mechanical structure, for example, is characterized by a consistent lightweight design with high effective stiffness. Lightweight servo actuators are used, and the resulting inertia of the legs is minimized by a sophisticated structure and drive mechanism design, resulting in superior acceleration behavior.

One of the NAO robot's DOF, located at the waist, is shared by its two legs. This modeling differs from the format used by most humanoid robots, in which there is a joint in the horizontal axis at the waist and rotating joints in the vertical axis for each of the legs. The model applied in NAO provides advantages to the robot, such as reduced walking problems and costs, because only one motor needs to be used to control the pelvis [24].

Therefore, to ensure that the robot achieves stable and fast locomotion, it is necessary to pay attention to the design of the robot's kinematic structure and to some design goals to improve the dynamics of its limbs.

Perception

Two groups currently classify the humanoid robot sensors: proprioceptive, which measures the state of each joint and the robot's body; and exteroceptive, which obtains information from the environment [1]. Internal sensors measure the robot's state, such as the joints' angles, velocities, and torques. IMU (Inertial Measurement Unit) sensors, including accelerometers and gyroscopes, detect information from the robot's posture. At the same time, the interaction between the robot and the environment can be detected through tactile and force/torque sensors. Furthermore, the cameras and range sensors measure and estimate the information around the robot [24].

In the design developed by Kien, Shanmugavel, and Ragavan, four ultrasonic sensors, two on each leg, are used for position feedback for walking and turning. The accelerometer measures the tilt angle and detects the robot's instantaneous fall. Resistive Force Sensors (RSF) are used to determine the center of pressure (COP), which in turn is used to calculate the robot's ZMP (Zero Moment Point) [25].

Thus, perception sensors are vital to allow robots to interact with the environment and people, and it is through the data obtained by sensors that the control systems are implemented.

Control

The first step for humanoid robot walking control is planning the footsteps and setting some parameters through a robot model. Four models are often used as an approximate representation of the biped robot. First, the Linear Inverted Pendulum Model (LIPM) considers that all the mass of the robot is concentrated at one point, moving at a constant height, and assumes that the legs are weightless. This model has been widely applied in various research, such as by Kashyap and Parhi [26], who used the particle swarm optimization (PSO) technique to refine the conventional PID controller and widely studied and applied by Kajita and colleagues [27].

Another model is the Inverted Pendulum with Flywheel (IPF), which does not consider the height constant and adds a flywheel to account for internal angular momentum. The Spring-loaded Inverted Pendulum (SLIP) adds a spring to model the legs of the robot as a mass-less jumper. Moreover, the Compass Gait Biped (CG) treats the robot as a double pendulum with masses concentrated at the center of mass (COM) and the swinging legs. Wahrmann and colleagues conduct the strategy in real-time control using a reduced robot model, making the robot more robust against perception errors and uneven surfaces [18-28]. Afterward, a trajectory generator must be implemented, which generates some movement considering the displacement of the mass center and the Zero Moment Point (ZMP) and the description of the inverse kinematics. Thus, the robot's joint angles are obtained, but a controller must stabilize them to ensure that the robot remains upright and performs all tasks without falling [26]. Kasaei et al.present a framework of a controller with a closed loop based on the Central Pattern Generator (CPG) method that proposes a control model inspired by biological features. In this way, this method tries to produce a stable gait through rhythmic patterns concerning the movement of its limbs. This test was performed on a simulated NAO robot with the proposal of generating a stable and fast movement [29]. Thus, there are several strategies under study that researchers and developers share to create more effective systems, which has allowed an advance in the performance of these robots.

Conclusion

There is growing research and implementation of anthropomorphic robots due to their numerous applications, as in the case at the Oakland airport and CloudMinds' works. Due to their human body shape, these robots can remarkably adapt to our environments. Furthermore, due to their endurance and strength, they can perform tasks difficult for humans. The humanoid robots whose main characteristics were presented, especially NAO and Lola, are reference models for the development of humanoid robots due to their application in research with innovative results, being addressed in several of the selected articles through the methodology applied. This research aids decision-making and serves as a starting point for further investigation into the techniques and procedures addressed.

In the future, more information can be added to the implemented documentation to aggregate and contribute to the development of other projects. This study was necessary for analyzing and learning about anthropomorphic robots, and the information provided is very relevant for developing new projects.

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References

1. He J, Gao F. Mechanism, actuation, perception, and control of highly dynamic multilegged robots: a review. Chinese Journal of Mechanical Engineering 2020;33(1):1-30.
2. Gupta S, Kumar A. A brief review of dynamics and control of underactuated biped robots. Advanced Robotics 2017;31(12):607-623.
3. Humanoid Robot Market Size, Share, Opportunities, Trends & Forecast. Verified Market Research, 2021. Available at: <http://www.verifiedmarketresearch.com/product/humanoid-robot-market/>. Accessed on: 13 Dec 2021.
4. Read B. Rise of the airport robots. Royal Aeronautical Society, 17 Aug 2017. Available at: <https://www.aerosociety.com/news/rise-of-the-airport-robots>. Accessed on: 02 Dec 2021.
5. Joseph A et al. A review on humanoid robotics in healthcare. In: MATEC Web of Conferences. EDP Sciences 2018:2004.
6. Clifford C. Look inside the Hospital in China Where Robots treated Coronavirus Patients. CNBC, 23 Mar 2020. Available at: <http://www.cnbc.com/2020/03/23/video-hospital-in-china-where-covid-19-patientstreated-by-robots.html>. Accessed on: 02 Dec 2021.
7. Chatterjee S, Chaudhuri R, Vrontis D. Usage intention of social robots for domestic purpose: from security, privacy, and legal perspectives. Information Systems Frontiers 2021:1-16.
8. DARPA Robotics Challenge (DRC). DARPA. Available at: <http://www.darpa.mil/program/darpa-roboticschallenge>. Accessed on: 02 Dec 2021.
9. Humanoid Robotics - IEEE Robotics and Automation Society. Ieee-Ras.org, 2019. Available at: <http://www.ieeeras. org/humanoid-robotics>. Accessed on: 02 Dec 2021.
10. Best Humanoid Award | RoboCup Humanoid League. Humanoid.robocup.org, Available at: <http://humanoid.robocup.org/league/best-humanoid-award/>. Accessed on: 02 Dec 2021.

11. Wieber P-B, Tedrake R, Kuidersma S. Modeling and control of legged robots. In: Springer handbook of robotics. Springer, Cham, 2016:1203-1234.
12. Bibliometrix.org. Bibliometrix. Available at: <https://www.bibliometrix.org/home/>. Accessed on: 22 Jul 2022.
13. Grames E. Litsearchr. Github.io. Available at: <https://elizagrames.github.io/litsearchr/>. Accessed on: 16 Out 2021.
14. Westgate M. Tools for Evidence Synthesis in R. Revtools. Available at: <https://revtools.net/>. Accessed on: 22 Jul 2022.
15. Reis M, Vale A. BILI Method - An optimization for literature and literature review. Github. Available at: <https://github.com/Brazilian-Institute-of-Robotics/bir-mini-bili-method>. Accessed on: 2 Dez 2021.
16. Elsevier. Scopus. Available at: <https://www.scopus.com/>. Accessed on: 16 Out 2021.
17. Putri DIH et al. Gait controllers on the humanoid robot using kalman filter and PD controller. In: 2018 15th International Conference on Control, Automation, Robotics and Vision (ICARCV). IEEE, 2018:36-41.
18. Wahrmann D et al. Modifying the estimated ground height to mitigate error effects on bipedal robot walking. In: 2017 IEEE International Conference on Advanced Intelligent Mechatronics (AIM). IEEE 2017:1471-1476.
19. SoftBank Robotics. NAO the Humanoid and Programmable Robot | SoftBank Robotics. Softbank robotics. Available at: <http://www.softbankrobotics.com/emea/en/nao>. Accessed on: 16 Oct 2021.
20. Trossen Robotics. Darwin-OP Delux Humanoid Robot. trossenrobotics. Available at: <https://www.trossenrobotics.com/p/darwin-OP-Deluxe-humanoid-robot.aspx>. Accessed on: 16 Oct 2021.
21. TUM. Humanoid Robot LOLA. Available at: <https://www.mec.ed.tum.de/am/forschung/aktuelleprojekte/robotik/humanoider-roboter-lola/>. Accessed on: 16 Oct 2021.
22. Wevolver. Hubo Humanoid Robot. Available at: <https://www.wevolver.com/specs/hubo.humanoid.robot>. Accessed on: 16 Oct 2021.
23. Buschmann T, Lohmeier S, Ulbrich H. Humanoid robot Lola: Design and walking control. Journal of physiology-Paris 2009;103(3-5):141-148.
24. Goswami A, Vadakkepat P (Ed.). Humanoid robotics: a reference. Dordrecht: Springer, 2019.
25. Kien EKT, Shanmugavel M, Ragavan SV. Motion planning of a bipedal walking robot with leg-mounted ultrasonic sensors—An experimental study. In: 2016 International Conference on Robotics and Automation for Humanitarian Applications (RAHA). IEEE 2016:1-6.
26. Kashyap AK, Parhi DR. Particle swarm optimization aided PID gait controller design for a humanoid robot. ISA Transactions 2021;114:306-330.
27. Kajita S. Simple modeling for a biped walking pattern generation. In: Proceedings of the International Conference on Intelligent Robotics and Systems, Maui, HI, USA, 2001.
28. Grizzle JW et al. Models, feedback control, and open problems of 3D bipedal robotic walking. Automatica 2014;50(8):1955-1988.
29. Kasaei SM et al. A hybrid zmp-cpg based walk engine for biped robots. In: Iberian Robotics conference. Springer, Cham 2017:743-755.