Studies in Systems, Decision and Control 344

Cengiz Kahraman
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# Toward Humanoid Robots: The Role of Fuzzy Sets

## A Handbook on Theory and Applications

Springer

# Studies in Systems, Decision and Control

Volume 344

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Editors

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ISSN 2198-4182 ISSN 2198-4190 (electronic)
Studies in Systems, Decision and Control
ISBN 978-3-030-67162-4 ISBN 978-3-030-67163-1 (eBook)
https://doi.org/10.1007/978-3-030-67163-1



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The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

*I dedicate this book to the medical doctors over the world who are struggling with the corona virus.*

*Prof. Cengiz Kahraman*

*I dedicate this book to my beloved parents, Müzeyyen and Nejdet and my brother Taha.*

*Dr. Eda Bolturk*

# Preface

Humanoid robots with their body shapes having a torso, a head, two arms, and two legs are the robots built to resemble all kinds of the movements of human body. Presently, humanoid robots are produced for functional purposes such as interacting with human tools and environments. For instance, a humanoid robot can work at a tourist information center. Humanoid robots may be also produced to resemble only a certain part of the human body. Some humanoid robots have heads designed to replicate human facial features such as eyes and mouths, whereas some humanoid robots have arms designed to do complex and toxic operations.

It cannot be stated that today's humanoid robots are very successful in imitating the movements of the human body. Real human emotions cannot be modeled by opening or closing their eyes while talking, moving them up or down or left and right. Humanoid robots must be able to express their emotions appropriately to what they see and/or hear. This can be possible using continuous logic, but never possible by discrete logic.

Fuzzy set theory based on a continuous logic has a great potential in modeling the movements and emotions of humanoid robots. Everything is a matter of degree in fuzzy logic. The facial expression of a person who becomes happy by hearing that her friend is married will be different from the facial expression of a person who is happy by hearing that her friend has successfully passed her Ph.D. exam. Hence, the way of smiling and its degree is different in each of these events. The vagueness and impreciseness in human thoughts can be captured by the fuzzy sets and their extensions.

The aim of this book is to present the theory and applications of fuzzy sets in modeling the movements and emotions of humanoid robots. This book involves 11 chapters, each written by the experts of that research area. The first chapter summarizes the present status of humanoid robots in the world. Besides, a literature review on humanoid robot publications is given and books, conferences, institutes, and journals on humanoid robots are presented.

The second chapter presents a comprehensive literature review on the recent developments and theories associated with fuzzy set extensions. The recently developed fuzzy set extensions from type-2 fuzzy sets to t-spherical fuzzy sets are classified and presented by their main definitions and operations.

The third chapter presents some fuzzy modeling techniques for facial expressions of a humanoid robot depending on the degrees of the emotions. Larger degree of emotion causes a stronger indicator of the facial mimic. Intuitionistic fuzzy sets and Pythagorean fuzzy sets are employed for modeling facial expressions.

The fourth chapter argues that to make sure that human-like robots exhibit human-like behavior, it is needed to use fuzzy techniques. The authors provide details of this usage. The chapter is intended for both researchers and practitioners who are very familiar with fuzzy techniques and also for researchers and practitioners who do not know these techniques—but who are interested in designing human-like robots.

The fifth chapter presents the metaheuristics methods used in the control of robots. A literature review and graphical analyses are given on this research area. The chapter shows that metaheuristics can be used as important building blocks in humanoid robots together with fuzzy set theory.

The sixth chapter tries to find the best-suited algorithm to narrow down future research in the field of test automation and provide issues on the design of new proposals. The authors focus on the performance evaluation of different major meta-heuristic algorithms, namely hill climbing algorithm, particle swarm optimization, firefly algorithm, cuckoo search algorithm, bat algorithm, and artificial bee colony algorithm. Each algorithm is implemented to automatically generate test suites based on the program under test. Then, we develop a performance evaluation of each algorithm for five programs written in Java. The algorithms are compared using several process metrics and product metrics.

The seventh chapter presents a comparative study using three types of controllers, FLC, PI and PID, applied to the speed control of a robot built using the ev3 Lego Mindstorms kit. MATLAB and Simulink are used to validate the performance of the speed control obtained with the proposed controller.

The eighth chapter maintains a specific location and behavior for a robot that uses type-2 fuzzy logic for controlling its behavior. The authors propose a combination of behaviors by following a trajectory without leaving or losing it and avoiding obstacles in an omnidirectional mobile platform. The results of the simulation show the advantages of the proposed approach.

The ninth chapter reviews the recent applications and research papers of humanoid robots related to fuzzy control. Studies about the humanoid robots and fuzzy logic-based control are grouped under four major topics; the first one is stability and reliability control, the second one is walking pattern detection, the third one is navigation, and the final one is obstacle avoidance.

The tenth chapter explains how the concept of single-valued trapezoidal neutrosophic (SVTN) numbers can be applied in the field of humanoid robotics. To explain the concept of SVTN numbers, a multi-robot scenario is considered consisting of a central server and a group of mobile robots patrolling a given area for surveillance application. Using the correlation coefficient of SVTN numbers, the sensor readings are properly interpreted for proper identification of the problem faced by the robot.

The eleventh chapter aims at highlighting the recent developments in the field of neutrosophic graph (NG) theory and their generalizations including neutrosophic hypergraph, interval NGs, bipolar NGs, etc. Almost all the work based on the development of NGs and their applications are discussed thoroughly.

We would like to thank the authors for their efforts in writing their studies and the anonymous reviewers for their hard works in selecting high-quality chapters in this book. We would like to express our sincere thanks to Prof. Janusz Kacprzyk for his continuous supports and helps.

Maçka, Istanbul, Turkey Cengiz Kahraman
January 2021 Eda Bolturk

# Contents

# Introduction to Humanoid Robots and Fuzzy Sets

# Humanoid Robots and Fuzzy Sets

**Eda Bolturk and Cengiz Kahraman**

**Abstract** Humanoid robot is a research area in robotics. Humanoid robots are shaped in order to resemble human shape. These robots are used for different purposes in different industries such as health, space, education and manufacturing. In this chapter, we try to summarize the present status of humanoid robots in the world.

**Keywords** Fuzzy sets · Humanoid robots · Types of humanoid robots

## 1 Introduction

Artificial intelligence (AI) used in robots is the theory and development of computer systems able to perform tasks normally requiring human intelligence, such as visual perception, speech recognition, decision-making, and translation between languages. People think of AI as a robot gliding around and giving mechanical replies. There are many forms of AI but humanoid robots are one of the most popular forms. One of the earliest forms of humanoids was created in 1495 by Leonardo Da Vinci. It was an armor suit and it could perform a lot of human functions such as sitting, standing and walking. Initially, the major aim of AI for humanoids was for research purposes. Now, humanoids are being created for several purposes that are not limited to research. Classical logic (0-1 logic) has been used in most of these robot technologies, causing rigid and sharp mimics of human behaviors. Discrete logic based technologies cannot imitate the continuous structure of human intelligence.

Present humanoids are developed to carry out different human tasks and occupy different roles in the employment sector. Some of the roles they could occupy may be the roles of a personal assistant, receptionist, front desk officer and so on. The process of inventing a humanoid is quite complex since it is absolutely hard to resemble human behaviors. Most times, inventors and engineers face some challenges. Humanoids move, talk and carry out actions through certain features such as

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C. Kahraman and E. Bolturk (eds.), *Toward Humanoid Robots: The Role of Fuzzy Sets*, Studies in Systems, Decision and Control 344,
https://doi.org/10.1007/978-3-030-67163-1_1

sensors and actuators. Humans behave based on a continuous decision making mechanism. Humans can rapidly select the appropriate behavior when they face any case among infinite number of possible cases. For instance, they can decide the degree of laughing when they face a comic case and the other body parts behave suitable to this degree.

Humanoid robots are designed to look like humans for intuitive collaboration, and the latest locomotion and AI technology is helping to speed up their development. Robots come in many shapes and sizes. But, perhaps, the most intriguing, endearing, and acceptable are the ones that resemble us, humans. Humanoid robots are used for research and space exploration, personal assistance and caregiving, education and entertainment, search and rescue, manufacturing and maintenance, public relations, and healthcare.

In the area of healthcare, it is quite clear that we need humanoid robots more and more today. As viruses like COVID 19 and chickenpox spread to the rest of the world, robots are being deployed in many countries. Some robots can help relieve tired nurses in the hospitals, do basic cleaning and deliveries.

Humanoids are usually either Androids or Gynoids [1]. An Android resembles a male human while gynoids resemble female humans. Humanoids have sensors that aid them in sensing their environments. These sensors can use crisp or fuzzy logic based Technologies. Fuzzy logic based control technologies are superior to the other discrete logic based technologies since every behavior of humans is a matter of degree which can be handled by a membership function. Some sensors have cameras that enable them to see clearly. Motors placed at strategic points are what guide them in moving and making gestures. These motors are usually referred to as actuators.

After the purpose of the humanoid robot is determined, robot researchers have to start the coding process which is one of the most vital stages in creating a humanoid. Coding is the stage whereby these inventors program the instructions and codes that would enable the humanoid to carry out its functions.

The robotics industry is improving day by day based on human requirements. Humanoid robotics is an emerging and challenging research field receiving significant attention during the past years. Professor Ichiro Kato from Waseda University and his colleagues developed the first humanoid robot in 1973. The name of the humanoid robot was WABOT-l [2]. Later, the WABOT-1 was differentiated to its different types: WABOT-2 developed in 1984 was a humanoid robot that could read a musical score and play an electronic keyboard and Hadaly-2 was intended to realize information interaction with humans by integrating environmental recognition with vision, conversation capability (voice recognition, voice synthesis) and the bipedal walking robot WABIAN was developed in 1997. Humanoid Robotics Institute was established for the connection of machines and humans in April 2000 [2] .

Honda started the humanoid robot research and development program in 1986. Honda's keys to the development of the robot were *intelligence* and *mobility*. The basic concept was that the robot should coexist and cooperate with human beings, by doing what a person cannot do and by cultivating a new dimension in mobility to ultimately benefit society. This provided a guideline for developing a new type of robot that would be used in daily life, rather than a robot purpose-built for special operations.

The first prototype of a man-like model with upper limbs and the body was called as P1. The robot could turn external electrical and computer switches on and off, grab doorknobs, and pick up and carry things. Coordination between arm and leg movements was also another research area. In December 1996, Honda introduced the P2, the most advanced humanoid robot ever built up to that time. The weight and height of P2 were 175 kg and 191.5 cm, respectively. P2 is considered the world's first self-regulating two-legged humanoid walking robot. P2's torso contained a computer, motor drives, battery, wireless radio and other necessary technology [2]. Independent walking, walking up and down stars, cart pushing and other operations were achieved without wires, allowing independent operations. Independent walking at 2 km/h, walking up and down stairs, cart pushing, and other operations were achieved without wires.

The weight and height of P3 were 210 kg and 182 cm, respectively. P3, which was the first completely independent, two-legged humanoid walking robot was completed in September 1997. The weight and height of P3 were 130 kg and 160 cm, respectively. The P3 is considered the world's first completely independent two-legged humanoid walking robot (2 km/h). The P3 was loaned to Japan's National Institute of Advanced Industrial Science and Technology (AIST) in 1998 to help kick start their Humanoid Robot Project. Further efforts were made to reduce size and weight, and improve dynamic performance and operability. ASIMO (Advanced Step in Innovative Mobility) is a humanoid robot created by Honda in 2000. It is currently Marikinain Tokyo, Japan. The name was chosen in honor of Isaac Asimov.

The aim of this chapter is to summarize the present status of the research on humanoid robots in the world. In addition, a literature review is presented in order to show the academic studies on humanoid robots.

The rest of the chapter is organized as follows. In Sect. 2, the types of robots are presented. In Sect. 3, humanoid robots and fuzzy logic relations are explained. In Sect. 4, today's humanoid robots are introduced. In Sect. 5, a literature review on humanoid robot publications is presented. In Sect. 6, books on humanoid robots are given. In Sect. 7, journals on humanoid robots are introduced. In the last section, the conclusions are presented.

## 2 Types of Robots

Robots are used for different reasons with different features. There are about 15 types of robots according to IEEE. They are presented as follows [3]:

- Aerospace
- Consumer
- Disaster Response
- Drones

- Education
- Entertainment
- Exoskeletons
- Humanoids
- Industrial
- Medical
- Military & Security
- Research
- Self-Driving Cars
- Telepresence
- Underwater

These types of robots are tried to explain shortly in the following.

**Aerospace:** They perform in space and flying robots are kind of these robots.

**Consumer:** These kind of robots are used in order to help in any chores and tasks.

**Disaster Response**: These robots perform in emergency situations for dangerous jobs and generally used for dangerous Works such as: earthquakes and tsunamis.

**Drones**: They can be called as remote-controlled aerial vehicles. Drones are shaped at various sizes.

**Education**: The education robots are generally used for the use in classrooms and at home. They are like teacher robots.

**Entertainment**: They are used in order to robots are designed to arouse emotional responses.

**Exoskeletons**: The robots are used for empowering paralyzed patient and physical rehabilitation.

**Humanoids:** These robots' appearance is like humans. Humanoid robots have androids and mechanical visual aspect.

**Industrial**: These robots are industrial and are used for execute iterative duties especially in warehouses and factories.

**Medical**: System of these robots is used in surgery and healthcare.

**Military & Security**: These robots include ground and autonomous mobile systems in order to transporting heavy gear.

**Research**: Research robots are used for doing functional things especially for helping researchers.

**Self-Driving Cars**: These robots are like cars as autonomous vehicles and they drive themselves.

**Telepresence**: These robots allow anyone to be a place without going to there via an avatar with the internet and anyone can communicate with others.

**Underwater**: These robots are featured for bio-inspired systems, diving humanoids, and, deep-sea submersiblest.

## 3 Humanoid Robots and Fuzzy Logic

Fuzzy logic presents opportunities for flexible modeling human behaviors. Otherwise, classical logic would cause more rigid and sharp movements on humanoid robots. Because of the usage of classical logic, inventors face a few challenges in creating fully functional and realistic behaviors. Some of these challenges include:

***Actuators*** These are the motors that help in motion and making gestures. The human body is dynamic. To make a humanoid robot, you need strong, efficient fuzzy controlled actuators that can imitate these actions flexibly and within the same time frame or even less. The actuators should be efficient enough to carry a wide range of actions [1]. Fuzzy set theory provides a soft modeling tool similar to human beings.

***Sensors*** Fuzzy logic is especially useful in the design of these components. These help humanoids to sense their environment. Humanoids need all the human senses [1]: touch, smell, sight, hearing and balance to function properly. The hearing sensor is important for the humanoid to hear instructions, decipher them and carry them out. The touch sensor prevents it from bumping into things and causing self-damage. The humanoid needs a sensor to balance movement and equally needs heat and pain sensors to know when it faces harm or is being damaged. Facial sensors also need to be intact for the humanoid to make facial expressions, and these sensors should be able to carry a wide range of expressions. In fuzzy sets, everything is a degree of matter. Their membership functions can model these expressions and movements through fuzzy control techniques in a continuous manner.

Humanoid robot technologies are secret technologies that what type of actuators and sensors, which artificial intelligence tools are used are not open. Fuzzy logic technologies are possibly used in the control of many humanoid robots of today. For instance, humanoid robot Pepper is so close to human thinking and perception style which is an indicator of the usage of fuzzy logic.

## 4 Today’s Humanoid Robots

Today’s humanoid robots are human-like and efficient to some degree. Here are a few of them.

**The Kodomoroid TV Presenter** This humanoid robot was invented in Japan. Her name is derived from the Japanese word for child—Kodomo—and the word ‘Android’ [4]. She speaks a number of languages and is capable of reading the news and giving weather forecasts. She has been placed at the Museum of Emerging Science and Innovation in Tokyo where she currently works.

**Jia Jia** This humanoid robot was worked on for three years by a team at the University of Science and Technology of China before its release. She is capable of making conversations but has limited motion and stilted speech. She does not have a full range of expressions but the team of inventors plans to make further developments and infuse learning abilities in her. Although her speech and vocabulary need further work, she is still fairly realistic [1].

**ASIMO** Advanced Step in Innovative Mobility, ASIMO for short, was created by HONDA in 2000, is a humanoid robot is designed in order to help to people. It is an entertainment and research humanoid robot and is from Japan. ASIMO which is Bipedal walking based on Zero Moment Point control approach, can dance, run, kick, jump, know faces, recognize speech and navigate human environments [5].

**The first robot citizen Sophia** Sophia is a gynoid humanoid robot and one of the popular humanoid robot in the world. She is the world's first robot citizen and granted Saudi Arabian citizenship. She was introduced to the United Nations on October 11, 2017. Hanson robotics created Sophia. She can do fifty facial expressions and her looking is very similar to human being. Sophia's AI aggregates cutting-edge operate in symbolic AI, adaptive motor control, neural networks, expert systems, cognitive architecture conversational natural language processing, and machine perception [6]. Sophia can identify faces of humans, see emotional expressions, and recognize various hand movements [6].

**Ocean One** This robot is invented by Stanford Robotics Lab and used in underwater. It is called bimanual underwater humanoid robot. Ocean one can go deeper in underwater and can explore places which humans cannot [7, 8]. It is stated that this robot dived 100 m below the Mediterranean sea in 2016. Ocean One investigated King Louis XIV's flagship which sank off the southern coast of France in 1664 [7]. It is stated that, Ocean One's system is the combination of artificial intelligence and haptic feedback systems and Ocean One's electronics are submersible in oil. This mechanisms aids to work under deep water [7].

**Pepper** This humanoid robot is created by SoftBank Robotics and a kind of educational robot. Pepper known as first social humanoid robot [9] Pepper can read human feeling for example sadness, anger and joy. It is stated that Pepper could communicate in intuitively and naturally and anyones' facial look and aspects. Different sensors are equipped in Pepper and this humanoid robot can discover and acquire about people [7]. Pepper offers an open and a platforms which is programmable. It has 20 degrees of independence in order to expressive and natural motion. It can speak in 15 languages such as English, German and Dutch and has the ability of speaking identification. There are perceptions modules in order to interaction with people. It has LEDs, touch sensors and microphones in order to interact multimodal and sonars, infrared sensors, one inertial unit, bumpers, 2D and 3D cameras, and sonars for navigation [9].

**Nao** It is a humanoid robot which is invented by Aldebaran Robotics and SoftBank obtained this humanoid robot [7]. NAO is used in research and education and assist visitors in healthcare centers in order to amuse, communicate and greet. NAO is worked with more than 600 best universities, labs, and secondary schools in the world [10]. NAO's 6 features are as follows. It offers an open and programmable platform. It has 25 degrees of independence in order to adapt and move. It can speak 20 languages such as English, German and Dutch and the ability of speaking identification. There are 4 directional microphones in order to interaction with people. There are 7 touch sensors which are placed in NAO's hands, head and feet. In order to understand NAO's environment, it uses 2 2D cameras, and sonars for navigation [11].

**ATLAS** It is created by Boston Dynamics and it is known as "the world's most dynamic humanoid" that is supervised by United States Defense Advanced Research Projects Agency (DARPA) [7]. The features of ATLAS are as follows [12]: 1.5 m height, 80 kg weight, 1.5 m/s speed, compact mobile hydraulic systems, 3D printed parts in order to add itself the strength-to-weight ratio necessary for tumbles and leaping, custom motors and valves, and advanced control system.

**PETMAN** PETMAN (Protection Ensemble Test Mannequin), was funded by US Department of Defense's Chemical and Biological Defense program, is created by Boston Dynamics and enhanced in order to examine chemical and biological teams for the US military [7]. The type of this humanoid robot's type is Military & Security humanoid robot [13]. This bipedal humanoid robot can squat and walk and do push-ups [13]. PETMAN's basic usage is for serving like a crash dummy of sorts for testing biological and chemical agents' effects and aid in any condition in biological or chemical war. PETMAN's features are as follows [13]: Anthropomorphic design, equipped with custom hydraulic actuators, 177.8 cm height, 79.4 kg weight, 6.44 km/h speed. It can alter its body temperature and humidity. Atlas is known as PETMAN's big brother. The other related humanoid robots with PETMAN are BEAR, TORO, HRP-4 and Robo Thespian.

**ROBEAR** Robear is a humanoid robot that was introduced by scientists from RIKEN and Sumitomo Riko Company Limited. This humanoid robot is bear shaped and is an an experimental nursing-care robot that is designed to lift patients out of beds and into wheelchairs, as well as helping those who need assistance to stand up [14]. The features of Robear are as follows [7]: 146 kg weigh, lighter than its earlier models RIBA (released in 2009) and RIBA II (released in 2011), integrated 3 kinds of sensors (includes smart rubber capacitance-type tactile sensors and torque sensors). In addition, Robear was seen as a potential solution to the problem of increasing lack of health care givers which Japan is set to observe.

**Surena** Surena is a research humanoid robot from Iran that is designed to in order to study artificial intelligence and bipedal locomotion. It's used to attract students to careers in engineering and provide entertainment at special events. The creator is University of Tehran. Surena can walk, pick up objects, dance, stand on one foot. climb, detect, recognize speech and do action imitation. The features of Surena are as follows [15]: 190 cm height, 46 cm length, 64 cm width, 98 kg weight, 0.7 km/h speed. It is said that Surena has 4 versions which are SURENA I (2008), Surena II (2010), Surena III (2015) and Surena IV [16]. Surena I had 8 degrees of freedom, Surena II had 22 degrees of freedom. SURENA III has 31 degrees of freedom [15].

**Robotic Avatar** Initially introduced by Toyota in 2017 [17], the T-HR3 is a humanoid robot that mimics the movements of its human operator, like a real-world avatar. Updated for Tokyo Olympics, the T-HR3 has improved controls and could walk more naturally. Envisioned as a mobility service, in the future these humanoids will be able to perform surgeries while their operators, human doctors, will be controlling them from another part of the world. It can also help caregivers to do their work remotely, or those in need of assistance to live a more independent life.

**Delivery Robot Digit** Ford became the first customer to incorporate Agility Robotics' Digit into a factory setting. The headless humanoid Digit has nimble limbs and is packed with sensors. It can navigate the stairs, various obstacles, and all kinds of terrains. It can balance on one foot, but usually it walks upright and is strong enough to pick up and stack boxes weighting up to 40 lb [18]. It can also fold itself for compact storage. Ford envisions that Digit will ride in a driverless car and deliver packages to customers, automating the whole delivery process [17].

**Digital Humanoids** Digital human beings look and act like humans but are entirely virtual. One example is Samsung Technology and Advanced Research (STAR) Labs' Neons [19], AI-powered beings with unique personalities and looks. These artificial humans are not designed to answer any questions like Alexa or Siri, but are supposed to show emotions, learn from experiences, and have real conversations. Each Neon is computer-generated and not necessisarly based on real people, and each can be customized for a different role, like a virtual doctor or a yoga instructor [17].

**Robotic Bartender** Kime is a food and beverage serving robot, developed by Macco Robotics in Spain. It has a human-like head and torso with two arms inside a kiosk. Tested at gas stations in Europe and in a Spanish brewery, Kime is known to be quite good at pouring beer and can serve up to 300 glasses per hour. The humanoid features 14 to 20 degrees of freedom, has smart sensors and uses machine learning to improve on its skills [17].

**Robotic Actor** Founded by director Will Jackson in 2004, Engineered Arts is a U.K.-based company that produces different entertainment humanoids through collaboration between artists, mechanical and computer engineers, and animators. For instance, their first humanoid—the well-known RoboThespian—is a robotic actor that comes with a library of impressions, greetings, songs, and gestures. The company is working on adding RoboThespian the ability to walk on its own, but for now the movement can be staged through a hidden system of tracks and dollies [17].

**Robonauts** Several countries have been working on humanoids for space exploration. In India, Vyommitra, a female humanoid robot, is set to launch on an uncrewed spaceflight in December 2020 [17]. The robot is scheduled to conduct microgravity experiments to help prepare for future crewed missions. NASA's Johnson Space

Center has worked on several humanoids, including Robonaut 2 (that spent seven years aboard the ISS) and Valkyrie. It's possible that future spacefaring humanoids will be designed to withstand harsh environments of the Moon or the Mars [17].

**Fedor (Final Experimental Demonstration Object Research)** It was a Russian remote-controlled humanoid that flew to the International Space Station (ISS) in 2019, where it simulated repairs during a spacewalk, and later returned back to Earth [17].

**Collaborative Humanoids** Most humanoids are intrinsically human collaborators. For instance, Nextage from Kawada Robotics is a humanoid research platform for industrial robots for Industry 4.0. Armar from Germany's Karlsruhe Institute of Technology was developed to perform maintenance tasks alongside human workers in industrial settings [18]. Walker by UBtech Robotics, on the other hand, is designed to collaborate with humans in their homes [17]. With seven degrees-of-freedom manipulators, the humanoid was developed to perform household tasks and smart home control.

**HRP-2** It was created by Kawada Industries and AIST in 2002 in Japan. It is a research humanoid. Yutaka Izubuchi was created HRP-2's exterior. HRP-2 can crawl, stand up, sit, cooperate with humans in lifting heavy objects, walk on uneven surfaces, and even get up by itself if it falls over. HRP-2 doesn't need a "power backpack" because of having electrical system and spherical compact battery. The features of HRP-2 are as follows [20]: 154 cm height, 33.7 cm length, 65.4 cm width, 58 kg weight, 2 km/h speed. It includes 30 motors in order to shift its waist, legs, head, and arms.

**Albert Hubo** It was created by KAIST and Hanson Robotics in 2005 in South Korea, is a research humanoid robot. Sadness, sadness and anger can be displayed from Albert Hubo's face and it is an origination of Hubo series. Albert Hubo's heads made by Hanson Robotics and the project of this humanoid robot was in the leadership of Professor Jun-Ho Oh [21]. The features of Albert Hubo are as follows [21]: 125 cm height, 57 kg weight, and 1.37 km/h speed

**Hubo 2** It was created by KAIST in 2009 in South Korea, is a research humanoid robot. This full size humanoid robot can do run, walk, grasp and dance. The features of Hubo 2 are as follows [22]: 125 cm height, 45 kg weight, 1.5 km/h walking speed, 3.6 km/h running speed, lightweight and modular design, and high performance actuation system.

**Mahru** It was created by Korea Institute of Science and Technology in 2005 in South Korea, is a research humanoid robot. This humanoid robot can walk, dance and do household tasks and Taekwondo. The features of Mahru are as follows [23]: 40 cm height, 65 kg weight, 1.2 km/h walking speed, recognizing objects. It faces and places, has autonomous and teleoperation modes, navigation rooms, avoidation obstacles.

**AR-600** It was created by Android Technologies in 2012 in Russia, is a research humanoid robot. This full size humanoid robot can walk, motion tools and objects and talk. The features of AR-600 are as follows [24]: 145 cm height, 65 kg weight, 2 km/h speed, recognition of objects and faces. The former versions of AR600 are AR-400 in 2006, AR-400 M in 2007 and AR-600 in 2008, respectively. The owner of these robots is belonged to Android Technologies [24].

**Erica** Erica (Erato Intelligent Conversational Android), was created by Osaka University, Kyoto University, and ATR in 2015 in Japan, is a research humanoid robot. Erica is an android humanoid robot and can find out natural language. The features of Erica are as follows [25]: 166 cm height, find the natural language, recognition of objects and faces, has compositive human-like voice, expressing facial aspect.

**Walker** It was created by UBtech Robotics, is a collaborator humanoid robot. It is laid out for collaboration in humans' homes. It is introduced for performing household tasks and intelligent home control along with seven degrees-of-freedom manipulators [17]. Walker can walk up and down stairs. Walker can move on all types of surfaces. Walker can detect and recognize corresponding faces, objects and environments in complex and background heavy situations [26].

**TALOS** It was a humanoid robot created by PAL Robotics. This humanoid robot is fully electrical and the fields of application are IoT, rescue, exploration of space. The usage areas are as follows [27]: Human-Robot interaction, Manipulation, Perception, Navigation, Torque Control, Artificial Intelligence, Machine learning, Trajectory optimization, Multi-contact motion planning, and Dynamic walking. The features of TALOS are as follows [27]: 175 cm height, 95 kg weight, 1.5 h walking/3 h stand-by battery autonomy, 6 kg arm stretched – arm/gripper payload, full torque sensor feedback in all joints, bipedal humanoid robot, head and Gripper fully customizable.

**REEM-C** REEM-C is a humanoid biped robot created by PAL Robotics. This humanoid robot can make a step when a force from adventitious force for not to fall. The usage areas are as follows [28]: Artificial Intelligence/Machine Learning, Dynamic Walking, Human-Robot Interaction, Manipulation, Multi-contact motion planning, Navigation, Perception, and Trajectory Optimization. The features of REEM-C are as follows [28]: 165 cm height, 80 kg weight, 1 kg hand payload, 3 h walking/6 h stand by battery autonomy, operating System based on Real Time OS, ubuntu LTS, speak 30+ languages, get up a chair and sit on.

## 5 Literature Review on Humanoid Robots

We search the "Humanoid Robot" term in Scopus and find 13.991 results. In Figs. 1, 2, 3, 4, 5 and 6, the literature review results of Humanoid Robots are given.

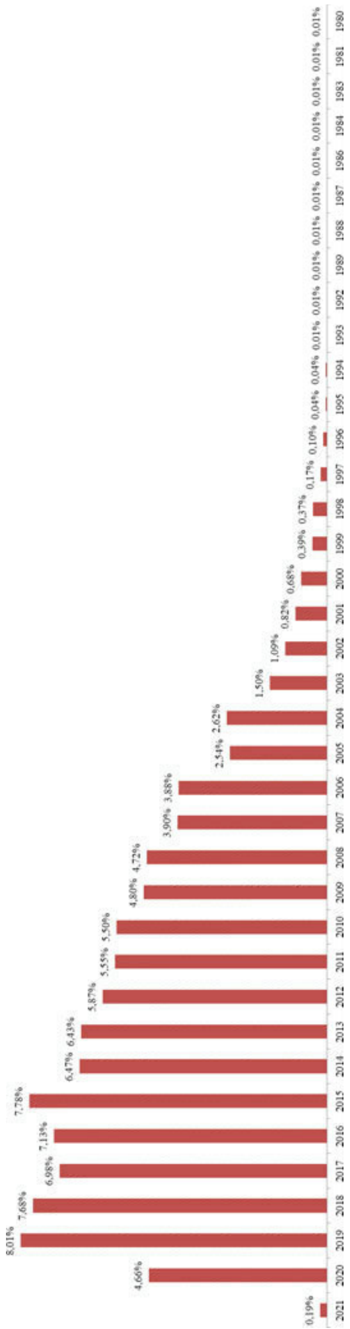


**Fig. 1** Distribution based on humanoid robot papers with respect to years

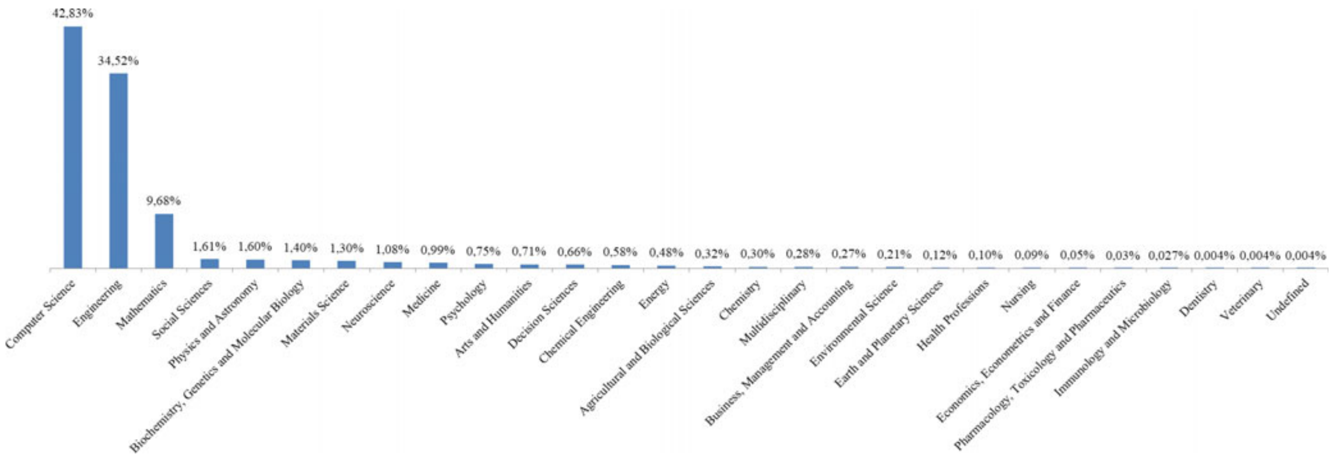


**Fig. 2** Distribution of humanoid robot papers with respect to subject areas

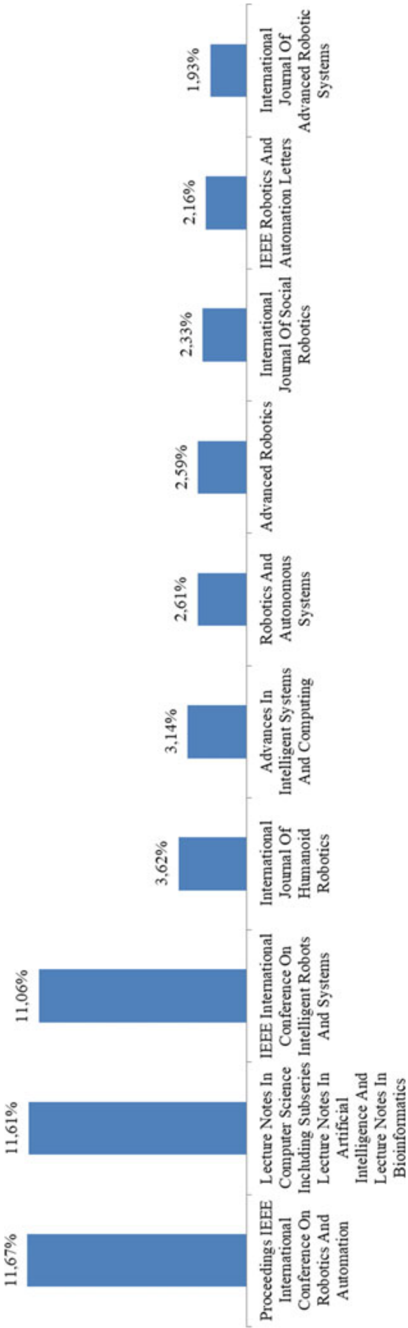


**Fig. 3** Distribution of humanoid robot papers by their sources

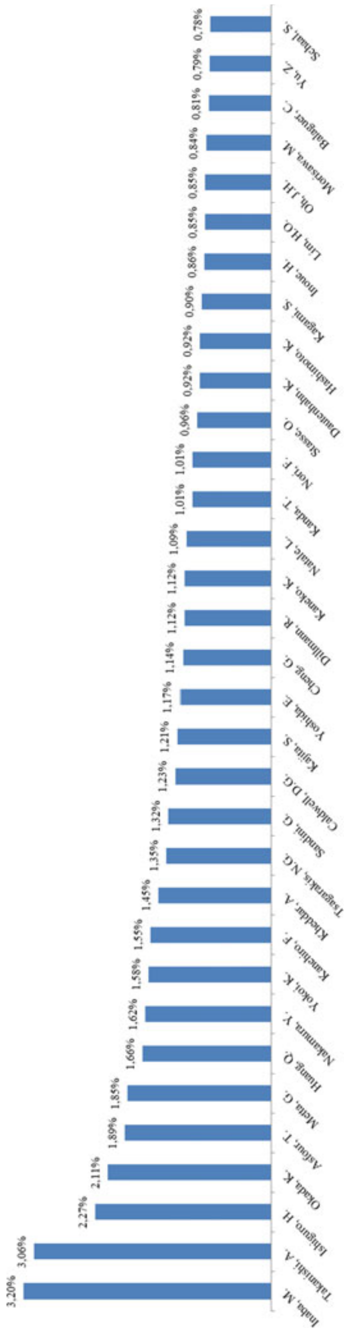


**Fig. 4** Distribution of publication percentages of authors on humanoid robots

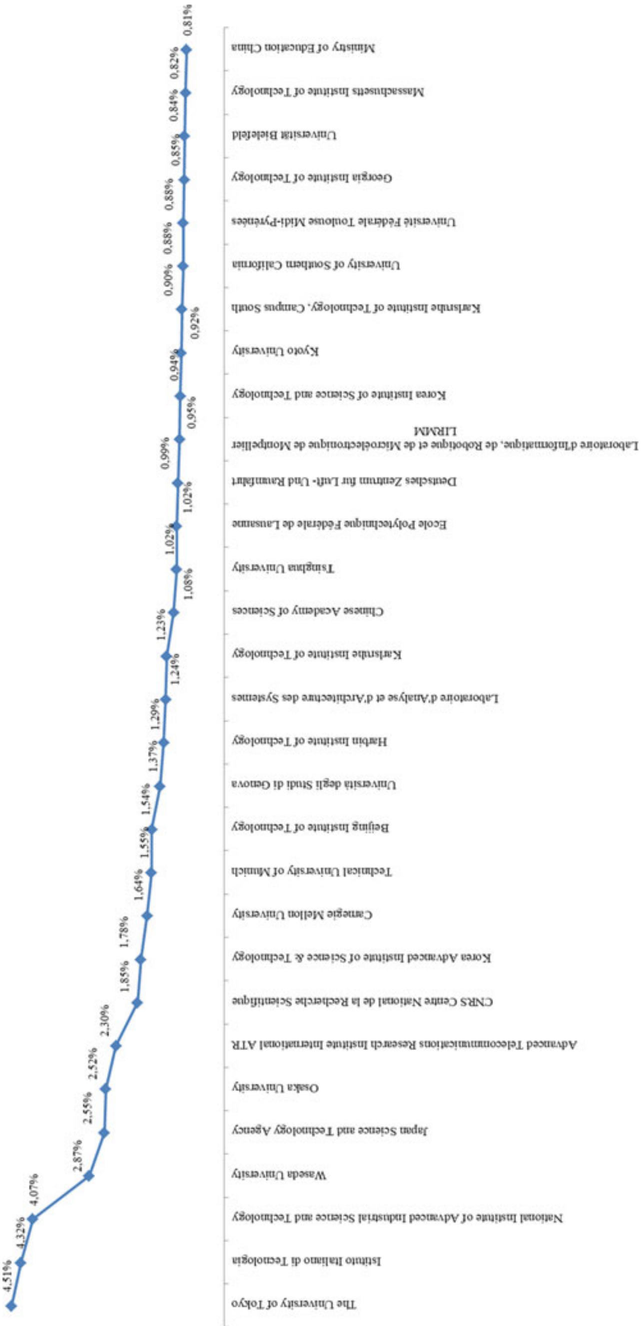


**Fig. 5** Distribution of affiliations on humanoid robot papers

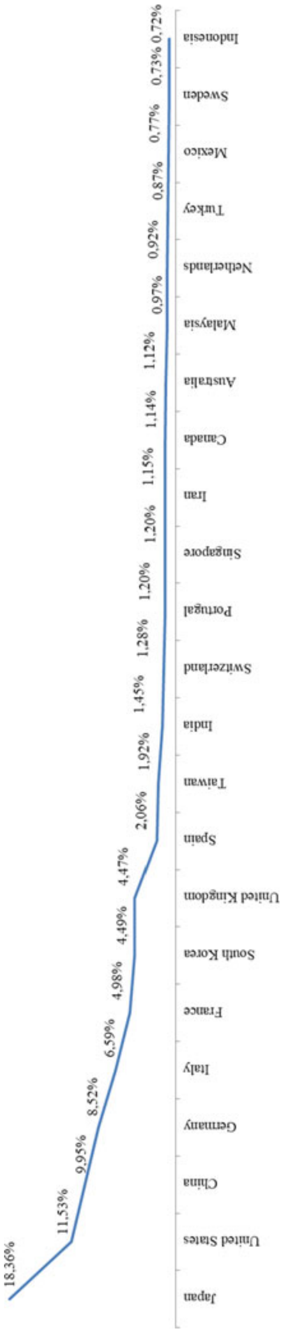


**Fig. 6** Distribution of humanoid robot papers by their countries

In Fig. 1, the distribution of papers by years is given. First paper is published in 1980. The most papers were published in 2019 with a rate of 8.01%. The percentage of published papers based on humanoid robots is increased substantially since 1998.

In Fig. 2, the distribution of humanoid robot papers is illustrated by their subjects areas. The most published subjects are computer science, engineering and mathematics, respectively.

In Fig. 3, the percentages of humanoid robot papers based on their sources are given. Most of the publications have been published in Proceedings IEEE International Conference on Robotics and Automation and Lecture Notes in Computer Science including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics.

In Fig. 4, the publication percentages and the corresponding numbers of authors on humanoid robot are presented. Inaba and Takanishi are the leaders among these authors.

In Fig. 5, the distribution of affiliations is presented based on humanoid robots papers. In addition to presented affiliations on Fig. 5, there are nearly 130 affiliations on these papers. The university of Tokyo and Istituto Italiano di Tecnologia are leaders among other affiliations.

In Fig. 6, the distribution of publications on humanoid robots with respect to their source countries is illustrated. Japan is the leading country on humanoid robots. United States and China are the next two countries after Japan, respectively.

The percentages and the corresponding numbers of humanoid robots are illustrated in Fig. 7. The document types on humanoid robots are: conference papers with a percentage of 64.16%, article with a percentage of 28.83%, conference review with a percentage of 3.17, book chapters with a percentage of 2.07, review with a percentage of 1, editorial with a percentage of 0.25, book a percentage of 0.16, note with a percentage of 0.11 and the others are erratum, short survey, letter and undefined ones.

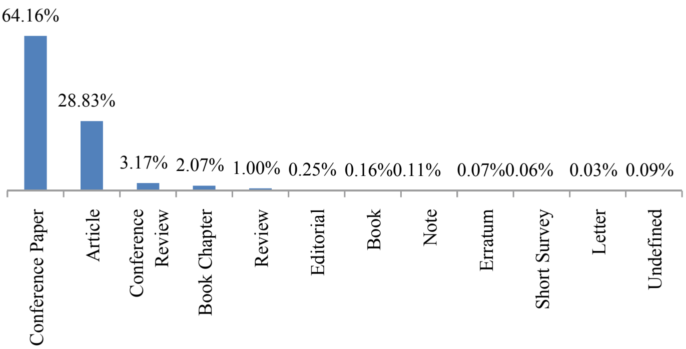


**Fig. 7** Distribution of humanoid robot papers by their types

## 6 Books on Humanoid Robots

The Books on Humanoid Robots are listed as follows:

- Introduction to Humanoid Robotics (Authors: Dragomir Nenchev Atsushi Konno Teppei Tsujita)
- Humanoid Robotics: A Reference (Editors: Ambarish Goswami, Prahlad Vadakkepat)
- Motion Planning for Humanoid Robots (Editors: Kensuke Harada, Eiichi Yoshida, Kazuhito Yokoi)
- Consciousness in Humanoid Robots (Editors: Antonio Chella, Angelo Cangelosi, Giorgio Metta, Selmer Bringsjord)
- Humanoid Robots: modeling and Control (Authors: Dragomir N. Nenchev, Atsushi Konno, Teppei Tsujita
- Artificial Intelligence and Humanoid Robots: 4D an Augmented Reading Experience (Authors: Alicia Z. Klepeis)
- Humanoid Robots: Running Into the Future (Authors: Kathryn Clay)
- Bringing a Humanoid Robot Closer to Human Versatility (Authors: Berthold Bäuml)
- Software Architectures for Humanoid Robotics (Editors: Lorenzo Natale, Tamim Asfour, Fumio Kanehiro, Nikolaus Vahrenkamp)
- Biologically Inspired Control of Humanoid Robot Arms: Robust and Adaptive Approaches (Authors: Adam Spiers, Said Ghani Khan, Guido Herrmann)
- Door Opening by a Miniature Humanoid Robot (Author: Bharadwaj Ramesh)
- Introduction to Humanoid Robotics (Authors: Shuuji Kajita, Hirohisa Hirukawa, Kensuke Harada, Kazuhito Yokoi)
- A Roadmap for Cognitive Development in Humanoid Robots (Authors: David Vernon, Claes von Hofsten, Luciano Fadiga)
- Humanoid Robotics and Neuroscience: Science, Engineering and Society (Editor: Gordon Cheng)
- Visual Perception for Humanoid Robots: Environmental Recognition and Localization, from Sensor Signals to Reliable 6D Poses (Authors: David Israel González Aguirre)
- Humanoid Robots (Author: S L Hamilton)
- Humanoid Robot Control Policy and Interaction Design: A Study on Simulation to Machine Deployment (Author: Suman Deb)
- Experimental Robotics IX: Experimental Robotics IX: The 9th International Symposium on Experimental Robotics (Editors: Marcelo H. Ang, Oussama Khatib)
- Evolutionary Humanoid Robotics (Author: Malachy Eaton)
- Whole-Body Impedance Control of Wheeled Humanoid Robots (Author: Alexander Dietrich)
- Online-Learning in Humanoid Robots (Author: Jörg Conradt)
- Pursh Recovery for Humanoid Robots Using Linearized Double Inverted Pendulum (Author: Saurav Singh)