Bibliometric analysis and visualization of research and development trends in humanoid robotics

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Abstract. This study searched the Web of Science core database for literature related to robotic arms for humanoid robots and used bibliometrics and CiteSpace 6.1.R2 software to visually analyze the authors, institutions, and keywords of the literature published in this field from 2009 to 2023. The study summarizes the current status and trends of robotic arms for humanoid robots and incorporates information extraction to select and include 376 articles for analysis. This study provides the field's development vein by reviewing the relevant literature and follows the research progress in the area of humanoid robots in a particular vein. In addition to thoroughly examining robotic arms and motion generating techniques for robotic arms that mimic human action, this study reviews pertinent literature. A review of the literature indicates a clear trend toward the use of artificial intelligence and machine learning to create motion control schemes for humanoid robotic arms. The report then assesses current methodologies and suggests future research directions for promising studies.

Keywords: humanoid robots, manipulator, human motion control, citespace.

1. Introduction

Humanoid robots, often referred to as robots that are close in shape to humans. Depending on the researcher, it can be defined as anything from a bipedal walker to a biarmed upper body robot [1]. In this essay, we emphasize humanoid robots with robotic arms that can carry out a variety of human tasks. These robotic humanoids are shaped like robots that can do certain human functions [2]. These robotic humanoid robots differ from bipedal walking humanoid robots in terms of development difficulties and application possibilities [3]. Manipulators are often designed for gripping, handling, and placing workpieces, but developing general-purpose manipulators capable of capturing foreign objects with different shapes and surface characteristics is a challenging task. Most robots favor multi-finger manipulators. However, this complicates both hardware and software [4]. With Industry 4.0 and Artificial Intelligence [5][6], the performance and application areas of robot manipulators are enhanced by a variety of intelligent control techniques that are used in robot manipulator systems. These techniques mimic human intelligence and include artificial neural networks, fuzzy logic control, expert systems, meta-heuristic algorithms, and machine learning control [7].

Robotic arm research has a rich history, having started with pioneering work in the 1980s. Using cutting-edge methods that have developed throughout time, researchers set out to improve the capabilities of robotic arms during this age.

The study was adequately supplemented with computer simulations, which the researchers utilized to explore and develop more effective and efficient control strategies for the robotic arm by examining the viability of each degree of freedom of the manipulator. The need for accurate and adaptable control techniques increased as a result of these developments, setting the stage for robotics' future [8].

Further forward in this pursuit was the early incorporation of sensors in robotic arm systems. Originally, it was believed that these sensors would assist in modifying the robotic arm's intended path. Robots can now adapt to changing circumstances and do jobs more correctly because of the embedded sensors, which is a significant advancement in the field [9].

The applications of robotic arms are widely distributed in various industries. In the field of aerospace, the International Space Station is equipped with the Canadian Mobile Servicing System (MSS), the Japanese Experiment Module Remote Manipulator System (JEMRMS) and the European Robotic Arm (ERA) [10]. Specialized harvesting robots for a variety of crops, such as apples [11], colored peppers [12], and even delicate strawberries [13], have been developed in the field of agriculture. In research [14] and industry [15], robotic arms are even more widely used [16]-[22]. Traditional rigid robotic arms [23] are heavy, expensive, inefficient, and even potentially dangerous, and researchers are favoring lightweight, flexible, flexibly linked robotic arms with soft joints or flexible parts that mimic living organisms[24][25]. Furthermore, in order to improve obstacle avoidance and self-adaptive capabilities, identify and place targets, and enable closed-loop control of the robotic arm to carry out the precise operation, redundant robotic arms [26] and machine vision technologies are introduced [27].

To expand the scope of robotic arm applications, various approaches have been explored. This includes the development of dual-armed collaborative robots [28], the integration of mobile robot platforms [29], and the implementation of demonstrative teaching or reinforcement learning techniques [30]. These endeavors aim to enhance the versatility and adaptability of robotic arms, making them suitable for a wider range of applications and scenarios.

Many excellent review papers focus on robots for medical or post-operative recovery [31], robots with soft grippers [32], robots for agricultural harvesting [33], robots that allow human-robot interaction [34], trajectory generation for humanoid arms [35], and vision-based human-robot collaboration [36]. Since artificial intelligence has made such rapid strides, the methods and research directions used in robotic arms have also advanced and changed with technology. As a result, a comprehensive overview of the state-of-the-art in robotic arm design and path planning is currently lacking. In order to increase the use of modern robotic arms in automation and human-computer interaction, as well as to attract the interest of researchers and engineers, it is necessary to present an overview of their development and application. By presenting and analyzing the relevant literature from a bibliometric perspective, our review seeks to increase the potential uses of various robotic arms and sensors in everyday life and also at the same time to help engineers and researchers in designing and selecting robotic arms. We compare and discuss the advantages and disadvantages of commonly used robotic arms and analyze the technologies used in these devices finally also give the problems and future directions of robotic arms.

2. Data and Methods

2.1 Data Source

Web of Science is the world's largest and most comprehensive academic information resource covering a wide range of disciplines, including the most influential 8850 (SCI) + 3200 (SSCI) + 1700 (AHCI) core academic journals in various research fields such as natural sciences, engineering and technology, biomedicine, etc. The impact factor (IF) introduced by Web of Science has now become an internationally recognized index for evaluating journals. The Impact Factor (IF) introduced by Web of Science has now become an internationally recognized journal evaluation index, which is not only a kind of index to measure the usefulness and display of journals, but also an important index to measure the academic level of journals and even the quality of papers.

2.2 Data Processing

We used the following search terms to identify documents in the field of robotic arms for humanoid robots for the search Searches title, abstract and indexing: manipulators, which yielded 27,883 papers, and then added the imperative keyword humanoid robots. In this first step, all subject areas and documents were included, and only works in the English language were selected. Given that Tsay's 2009 article, "Development of a Humanoid Robot," was the first to be deemed helpful [37], we chose to use this as the starting time and up to 2023. According to web of science, the annual production of papers related to this study has grown significantly since 2015 and is set to explode in 2020. As a result, we obtained 1015 papers. In the second step, we focused on the field of robotics and automation control, since robotic solutions in astronomy or neuroscience are not within the scope of our study, and added the following search terms by means of the Boolean "with" function: "Robotics ", "Automation Control Systems", "Computer Science", "Engineering" and "Robotics". Engineering" and "Mathematics". By filtering in the second step, we got 610 relevant papers. In the third step, we want that we consider high quality literature. Therefore, we select "Article", "Review Article", "Early Access" and "Meeting" for the source type. "Meeting". In order to focus our research on the robotic arm of the bionic robot, we manually screened the source literature, and finally we obtained 376 relevant papers as the basis of our research. We would like to mention that it is possible that the core topics are not in the search terms and published in non-robotics journals, and some related works may not be considered to address the mentioned topic areas.

2.3 Data Analysis Tools

CiteSpace software, short for Citation Space, is an information visualization software based on the theory of citation analysis developed by Chaomei Chen, professor of computer science and intelligence at Drexel University, based on Java language. The software can present the structure, law and distribution of scientific knowledge, and the analyzed graph is called "Scientific Knowledge Atlas", which is mainly used for writing review papers, sorting out theoretical viewpoints, evolution paths, development trends, academic history, etc. and scanning hot spots in the academic research field, etc. It is a practical literature analysis software for quantitative analysis.

3. Analysis of Results

3.1 Publication Volume Trend Analysis

The publication of literature is typically thought of as a key indicator of a discipline's state of development and research output. In the case of robotic arms for humanoid robots, the yearly number of publications can also, to some extent, predict the direction of future development.

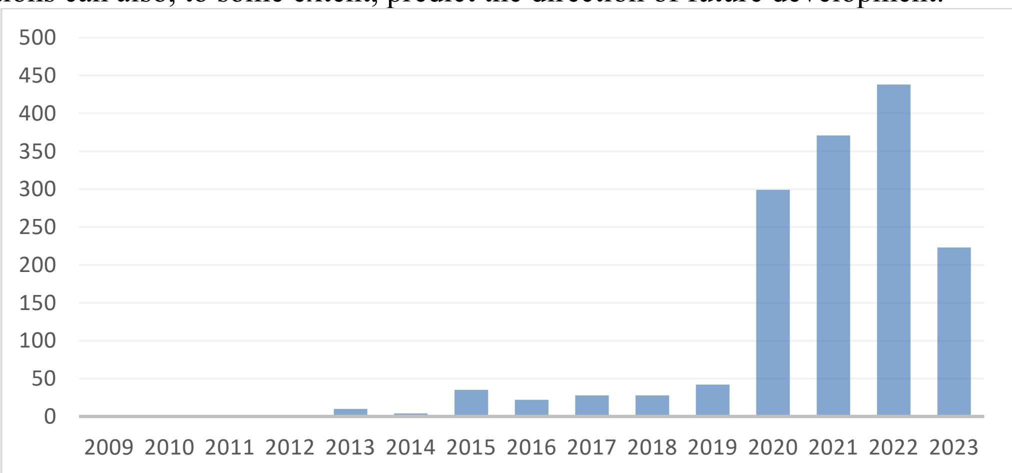

Fig.1 2009-2023 Number of published papers on robotic arms for humanoid robots

From Fig.1 2009-2023 Number of published papers on robotic arms for humanoid robots, this field of research has grown rapidly in recent years, particularly after 2020 when the scope and output of the field's studies seemed too dramatically increase. There are three stages to the publication volume: From 2009 to 2014, there was a slow germination period, with an average of only 2.6 publications published annually. The years 2015 to 2019 saw a period of erratic growth, with a notable spike in publications compared to the previous period, culminating in a milestone peak of 35 publications in 2015. The average number of publications annually has reached 31 publications. The two most highly cited publications in 2015 were S.M. Anzalone's Evaluating the Engagement with Social Robots [38] and J. Rios-Martinez's from Proxemics Theory to Socially-Aware Navigation: A Survey, which examined society's attitudes toward humanoid robots [39]. The latter study examined the majority of people's elevated interest in humanoid robots. The amount of literature published in this field of study is growing at an explosive rate between 2020 and 2023. The cumulative number of articles published in this phase is 1,331, and the average annual number of articles is 332.7; these figures are 127.98 times and 10.73 times, respectively, greater than those published in the first and second phases. The articles published in the last four years make up approximately 88.6% of the total number of articles published in the last four years. The development of computer algorithms and artificial intelligence technology, which offer stronger support for the creation and management of humanoid robots, is mostly to blame for this. Simultaneously, the use of bionics concepts has allowed robots to emulate human morphology, movement, and perception more closely. Better material options are also made possible by advanced material technologies while building humanoid robots. The field of humanoid robots is experiencing new development momentum as a result of this cross-pollination of emerging technology.

3.2 High Citations Frequency Journal Analysis

Highly cited journal analysis can be used to investigate the impact of journals, identify cutting-edge hotspots, identify top journals, and examine the structure of a research field, and this section examines the journals in which a sample of 376 documents were published. According to the Centrality of published papers throughout all the literature samples, the top 10 journals are displayed in Table, the frequency table of highly cited journals. A node's effect in the network can be measured using a metric called centrality, whose value increases with node influence. IEEE INT CONF ROBOT total citations 236, centrality: 0.11, the journal has the highest total number of citations and relatively high centrality value, indicating that it plays a core leadership role in the research of the field. IEEE INT C INT ROBOT total citations 196, centrality: 0.04, the journal has a higher total number of citations and lower centrality value. IEEE INT C INT ROBOT, total citations: 196, centrality: 0.04, the journal has a high number of total citations and a low centrality value, which suggests a certain degree of journal impact, but does not occupy a central position in a specific research subfield IEEE T ROBOT total citations 189, centrality: 0.12, Int J Robot Res total citations 178, centrality: 0.09, these two journals have higher centrality values, although the total number of citations is slightly less than the first journal, its centrality indicates that it has a high influence and top researchers and core theories in the research network.

Table 1. Frequency table of highly cited journals

NO	Journal Title	Centrality	Total Citations
1	IEEE INT CONF ROBOT	0.11	236
2	IEEE INT C INT ROBOT	0.04	196
3	IEEE T ROBOT	0.12	189
4	INT J ROBOT RES	0.09	178
5	IEEE ROBOT AUTOM LET	0.02	159
6	IEEE-RAS INT C HUMAN	0.08	147
7	ROBOT AUTON SYST	0.07	136
8	AUTON ROBOT	0.08	110
9	IEEE ROBOT AUTOM MAG	0.03	93
10	INT J HUM ROBOT	0.05	80
10	IEEE-ASME T MECH	0.03	80

3.3 Author Collaboration Analysis

By profiling the group of authors in the literature sample, the level of talent and the structure of collaboration in the field was assessed based on various elements such as the authors' outputs, influence, and collaborative relationships.

After the authors of the sample of 376 papers were examined, Table.2 reveals that Kanehiro Fumio ranked first with 8 papers, making him the most productive author in the field of research. The average number of papers was 5, indicating that the field is still in its early stages of development and that the group of authors is still relatively small in terms of size and accumulation.

Table 2. Top 10 authors in the field humanoid robots by number of publications

NO	Name	Documents Numbers
1	Kanehiro, Fumio	8
2	Okada, Kei	7
3	Inaba, Masayuki	7
4	Calinon, Sylvain	5
5	Asfour, Tamim	5
6	Kheddar, Abderrahmane	5
7	Morisawa, Mitsuharu	4
8	Billard, Aude	4
9	Benallegue, Mehdi	4
10	Hoffman, Enrico Mingo	4
10	Kawaharazuka, Kento	4

Price derived the following formula based on Rockwell's law, borrowing from mathematical conclusions：

$$M = 0.749 * N1/2 \quad (1)$$

M is the minimum publication standard to measure the core authors in the field, and N is the maximum number of publications by the highest authors in the field. The significance of this formula is that the number of publications by the least prolific one among the distinguished scientists is

equal to the square root of the number of publications by the most prolific scientists by a factor of 0.749, the authors who have published more than M can be considered core authors.

In Table.2, the value of N is 9, which is calculated as M≈2.18. The results show that the number of papers published as core authors is 3 and above. The statistics show that the top 10 authors are core authors who have laid the academic foundation for research in this field.

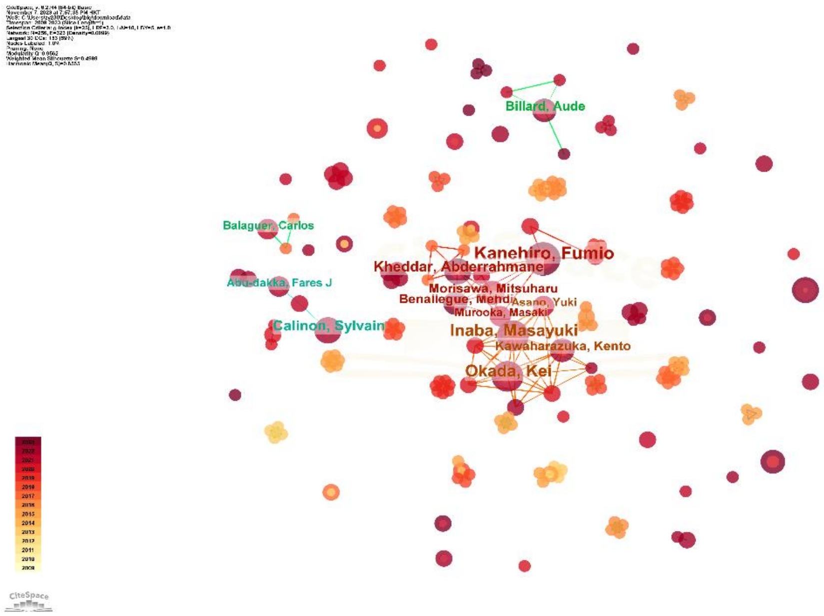

Fig.2 Authors cooperation network map

Fig.2 shows the core author cooperation network, the name in the network shows only the core group of authors who have issued more than or equal to 3. The color shades in the figure represent the size of the year of issuance, the connecting line represents the cooperation relationship, the bigger the author's name and the bigger the circle represent the more the amount of issuance. It can be seen that the three authors with the largest number of publications, Fumio Kanehiro; Kei Okada; Masayuki Inaba, have formed a core circle, who have become leaders in the field of robotic arms for humanoid robots, and their research on manipulation planning algorithms [40], gait manipulation planning [41], and bipedal control strategies for gait manipulation of humanoid robots [42] has a wide range of influences, and the results of their research provide references and opportunities for collaborations among researchers.

The table also shows that there are many groups of authors with a small number of publications, who collaborate with each other but are not connected to each other as a group, which fits with the multidisciplinary and multidisciplinary integration of the robotic arm, and who try to develop their research from other aspects. For example, Sylvain Calinon controls humanoid robots with learnable graph attention network (GAT) models from a learning demonstration-based approach [43].

3.4 Institution Collaboration Analysis

By analyzing the institutions that publish articles, we can identify the core research institutions in the field, and establish an important cooperation network through the cooperation relationship between institutions to expand the academic influence.

Table 3 Top 10 Organizations by Publication in Humanoid Robotic Arms

NO	Institution	Documents Numbers
1	Istituto Italiano di Tecnologia - IIT	19
2	Harbin Institute of Technology	15
3	Centre National de la Recherche Scientifique (CNRS)	14
4	National Institute of Advanced Industrial Science & Technology (AIST)	14
5	University of Tokyo	13
6	Chinese Academy of Sciences	12
7	Helmholtz Association	11
8	Ecole Polytechnique Federale de Lausanne	9
9	Swiss Federal Institutes of Technology Domain	8
10	Beijing Institute of Technology	8

Table.3 reflects the current multipolar development of this research field, with 19 articles published by the Istituto Italiano di Tecnologia. This indicates that IIT plays a leading role in the field of humanoid robotics. Harbin Institute of Technology, Chinese Academy of Sciences, and Beijing Institute of Technology from China published a total of 35 articles, China is the country that published the most articles, which indicates that China has a wide range of research in this field. Center National de la Recherche Scientifique (CNRS), National Institute of Advanced Industrial Science & Technology (AIST), University of Tokyo, Helmholtz Association also published more than 10 articles, which shows that researchers in the field of humanoid robotics have published widely and are very enthusiastic about the development of humanoid robots.

Fig.3 shows the main research directions and collaborations of the research organizations. The figure shows that Istituto Italiano di Tecnologia- IIT in Italy, Centre National de la Recherche Scientifique (CNRS) in France, National Institute of Advanced Industrial Science & Technology (AIST) in Japan are working closely together. CNRS, as a traditional research leader, is leading the way in researching the social aspects of humanoid robots, conducting social research [44] and attempting to make robots with high acceptance by the general public [45]. AIST mainly researches on the technical aspects of robotic arms, including soft robotic arms [46] and motion planning of robotic arms [47]. IIT's research is mainly in the medical field, including robotic arms for surgery [48] and social robots for the treatment of mental illness [49].

Several research institutions in mainland China work closely together, with a few collaborations with the University of Tokyo in Japan and the Hong Kong Polytechnic University in China, where independent research is strong. The main direction of research in mainland China is the combination of robotic arms with various sensors or materials to achieve better performance [50]-[53], belonging to the results of cross-disciplinary, in the Beijing University of Aeronautics and Astronautics also includes the research of space robotic arms [54]. The University of Tokyo, through neural network technology to make humanoid robots move more like people, and also from the multimodal approach to greatly improve the level of movement of humanoid robots [55][56].

Fig.3 Institutional Research Collaborative Network

The information of cooperation between countries can reflect the influence of the country in the field, the closeness of cooperation between countries represents the direction of key international cooperation, and international cooperation has a great role in promoting the progress of research. fig.5 is the network of national cooperation relationship, the size of the circle indicates the amounts of publications, the connecting line represents the cooperation relationship, and the thickness of the connecting line indicates the depth of the cooperation relationship. In this network, there are a total of 54 nodand es, and 122 connecting lines, and the connection density is 0.0853. There are a total of 54 countries in the graph, and the 122 lines indicate a closer cooperation, but the low density indicates that only a few countries have close cooperation, and most of the countries have fewer connections.

In Fig.4, the top 10 circles in order of size are PEOPLES R CHINA, JAPAN, USA, GERMANY, ITALY, ENGLAND, FRANCE, SPAIN, SOUTH KOREA, SWITZERLAND, among which the size of China is the largest and there is a significant difference in the size of China's circle with the others, which indicates that China has the highest influence in the field of humanoid robots. Robotic arms have the highest influence in the field of humanoid robots, and the many and deep lines between China and other countries indicate that the development of robotic arms in China has very sufficient communication with the international. Robotic arm and industrial applications have a close connection, more research on robotic arm often means the level of industrial development, in the figure the largest PEOPLES R CHINA, JAPAN, USA, GERMANY is traditionally known as the industrial production of large countries, these countries have advanced industrial manufacturing and mechanical engineering foundation, accumulated a large number of robotic arm design, control and related scientific research personnel.

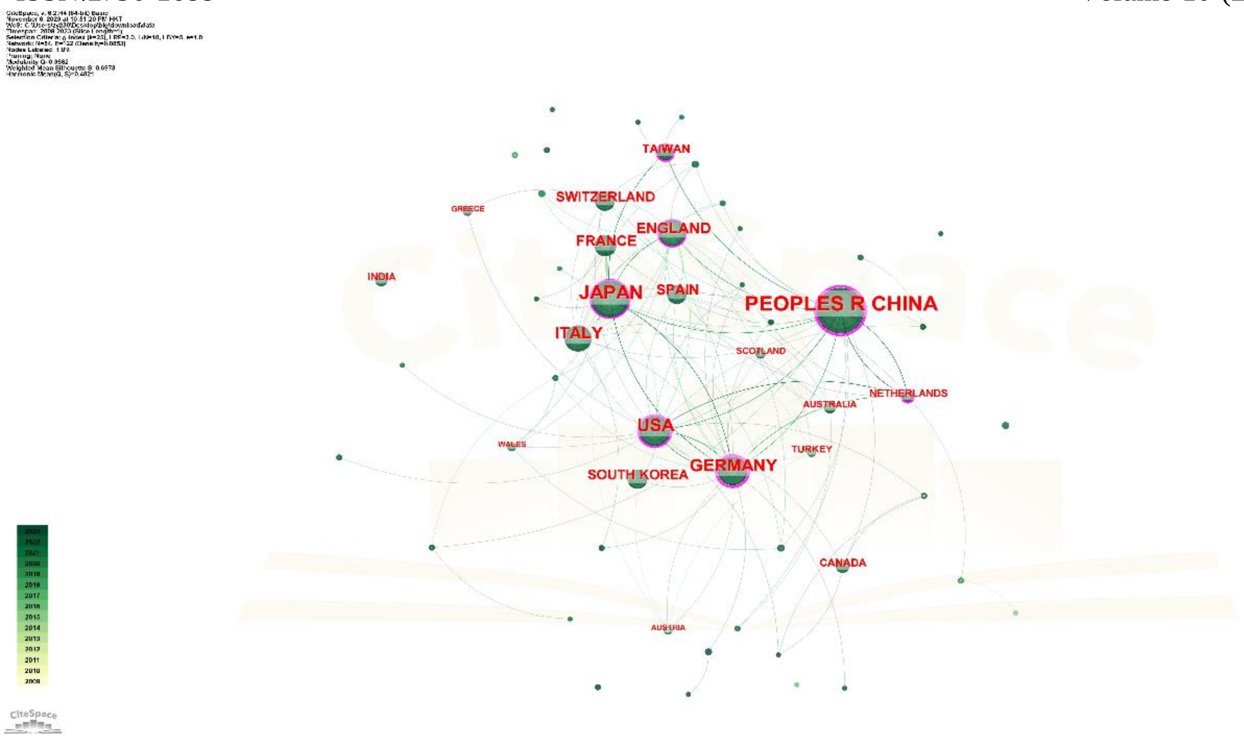

Fig.4 Country cooperation networks

3.5 Keywords Co-occurrence Analysis

Keyword analysis can dissect the research dynamics and development direction from multiple dimensions to understand the research frontiers and focuses. In Table.4, design, human-robot interaction, task analysis, motion, robot sensing systems, learning from demonstration, robot kinematics, inverse kinematics, imitation learning, and behavior are the popular research directions and technologies for humanoid robotics. These keywords accurately convey that there is a cross-fertilization development trend in the field of robotic arms research for humanoid robots, encompassing cutting-edge fields like computer vision, mechanics, control, and human-computer interface.

Table 4 Top 20 keywords for robotic arm research for humanoid robots

NO	Keywords	Occurrence frequency
1	humanoid robots	50
2	design	48
3	human-robot interaction	36
4	task analysis	26
5	robot	25
6	motion	25
7	humanoid robot	24
8	manipulators	19
9	optimization	17
10	robot sensing systems	16
11	learning from demonstration	14
12	robot kinematics	14
13	systems	14
14	inverse kinematics	13
15	system	13
16	model	13
17	manipulation	12
18	imitation learning	11
19	legged locomotion	11
20	behavior	11

TacSuit developed by Yanmin Zhou carries a variety of pressure, proximity, acceleration, motion, and temperature sensors, and greatly improves the safety of human-robot interaction through data fusion computational algorithms [57]. Jenny L Davis tries to reduce the discomfort of human-computer interaction from the socio-psychological aspect [58].

Task analysis is also the main research object of humanoid robots, and humanoid robots can be more closely matched with practical applications through the study of requirements [59]. 2.5D manipulation planner developed by Yili Qin can manipulate long and deformable objects, which is often used in industrial production. The 2.5D manipulation planner developed by Yili Qin can manipulate long deformable objects, which are often needed in industrial production. Yonggan Yan has developed a PG2 Gripper to realize flexible gripping, force sensing, and hand manipulation capabilities of grippers [60], which is a great advancement to the existing grippers. In the real world, the control of a robot depends heavily on the model of the environment and the dynamics of the robot, Farshad Khadivar proposed a quadratic programming (QP) based controller that can adjust the QP online to account for model uncertainties and unforeseen disturbances, which greatly aids the robot's ability to work in different environments [61]. Controlling the motion of robots also a very hot topic, Seyed Adel Alizadeh Kolagar proposed Learning from Demonstrations, a pioneering technique that allows robots to learn to generate 3D motion from 2D data [62], achieving similar results with expensive sensors at a much lower cost, and it can be predicted that this technique will be widely used in motion control with fewer data, for example, Younghyo Park's design of an iPad drawing robot, in which he generates the motion of a robotic arm through video learning [63]. The dexterous movements of manipulators are often driven through high degrees of freedom; Chun-Tse Lee proposed an improved gripper to reduce the need for degrees of freedom, and his results demonstrated the usability of FASA fingers for adaptive motion [64]. Robotic applications also include rescue efforts for disasters, and Xin Shu designed Dexbot, a track-legged humanoid robot that can adapt to a variety of ground environments [65].

The degrees of freedom (DOF) on many humanoid arms are six, and those with seven or eight DOF are intended to provide a greater range of motion or structural. To further versatility and complexity, Jaesoon Lee designed a 9-degree-of-freedom arm to improve performance [66]. Zelin Huang and Vincent Bonnet improved performance through whole-body control, which suffers from a lack of torque feedback, and used spatial inverse dynamics and variable contact force control to improve adaptability to unknown perturbations. Zelin Huang uses spatial inverse dynamics and variable contact force control to improve the robot's adaptability to unknown perturbations [67], while Vincent Bonnet uses whole-body elasticity to resist the effects of torque [68]. Feifei Zhong is more direct with a closed-form solution for each rotational joint angle, which allows the humanoid arm to mimic the human arm the closest, and the closed-form solution allows the robotic arm to map the motion of the human arm in real-time, giving a direct solution for the robotic arm to mimic the human arm [69]. Human-like motion gives the most direct solution. Mahdi Javadi uses a bionic approach, the humerus robot utilizes a unique underdriven motion pattern to broaden the deployment scenarios for humanoid and animal robots [70]. Zhehao Jin controls the motion through a mathematical approach, the Gaussian process movement primitive (GP- MP) is a novel non-parametric movement primitive that allows the movement to be completely data-driven [71]. Researchers are constantly optimizing the structure and control of the robotic arm to make its movement more flexible and adaptable to external complexities, making humanoid robots more humanoid.

4. Research Findings

The purpose of this part is to provide an extensive overview of the many approaches and research mediums used in the field of motion planning for humanoid robots in order to simulate human motion. The challenge of developing item manipulation skills in humanoid robots is extremely difficult, and the majority of robots currently in use either use task-oriented end grippers, and high degrees of freedom or replicate human joint mobility by maximizing various performance criteria.

4.1 Robot Manipulators

The research on humanoid robots never stops, many robots in different directions are developed and perform different tasks or come up with new ideas to solve specific dilemmas, and this research makes humanoid robots more anthropomorphic.

Soft robots and actuators have considerable promise in the field of humanoid robotics. Human-like movement requires a great deal of flexibility, and soft robots happen to have excellent flexibility and are lightweight, and the low price is also widely favored by researchers, as opposed to traditional rigid robotic arms that require increasing the degrees of freedom of the robotic arm to improve flexibility, which brings a significant increase in cost. However, because of its flexibility, the motion control algorithms for soft robots are very demanding, which is a great challenge for researchers. Moslem Mohammadi proposed a way to combine rigid and flexible materials to improve controllability, and changing the required rigidity with the actual working requirements can greatly reduce the difficulty of control [72]. Wu Ji Liu used a similar approach to develop a flexible robotic manipulator (FRM) that can achieve precise control of object grasping without relying on external sensors and can be adapted to narrow and unstructured environments. Wuji Liu used this similar approach to develop a flexible robotic manipulator (FRM) that can precisely control object grasping without relying on external sensors and can be adapted to move in narrow and unstructured environments [73].

From a bionic perspective, the most straightforward robotic arm design for humanoid or anthropomorphic robots would be controlled by muscles and bones. musculoskeletal robotic hardware and neural control software have been around for decades, and one of their most notable advantages is the lightweight and low inertia of their actuators. Ryota Kobayashi used a 4/3 muscle-wrapping approach to create the bending module. A six-rod tension robot with thin McKibben muscles can be made to bend approximately 45 degrees in six different directions, with controlled stretching and contraction for pick-and-place tasks [74]. In the medical field, where minimally invasive surgical robots (MISRs) have become a cutting-edge development for precision surgery, Jin Sun has developed self-helix twisted artificial muscles (SHTAMs) to drive MIRS with greater flexion and higher precision. Kinematic analysis trajectory tracking tests and experiments on sinusoidal trajectories with different frequencies and amplitudes were performed to determine the prospects for application in minimally invasive surgery [75].

In the research of different kinds of manipulators, there are a lot of novel designs that bring enhancement to the performance of manipulators. Toshihiro Nishimura proposes motor-driven robotic grippers, which are capable of gripping and rotating in confined spaces [76]. Dong Mei displayed an exceptionally anthropomorphic and dexterous soft-pneumatic hand. All 33 of the GRASP taxonomy's grasping types have been experimentally realized thanks to a hand model that has 21 degrees of freedom and articulated fingers and palms combined with a layered design that separates each individual actuator into an actuation layer and a contact layer that can be changed in real-time for both grasping modes and contact modes [77]. Facing complex assembly tasks and requiring stronger load capacity, single-arm robots are difficult to complete efficiently, in the application of deep reinforcement learning, dual-arm robots are valued by researchers. Da qi Jiang proposed an algorithm to simulate and then move to the real environment, using Proximal policy optimization (PPO) to train in a simulator, and then specifying the generative adversarial imitation learning (GAIL) to implement the model in reality [78]. Yiming Jiang used a base function neural network (RBFNN) to study the neural network [79], and then based on the integration of the neural network regression history data to update the Wu bin Shi used an improved algorithm based on the goal probability bias and cost function in a rapidly-exploring random tree algorithm (GA_RRT) to control the dual-armed robot and then verified the dual-armed robot on MATLAB. The effectiveness of the obstacle avoidance path planning problem of the dual-arm robot is verified on MATLAB [80].

4.2 Motion Control

The use of Machine Learning, Neural Networks, and Reinforcement Learning has provided new ideas for the control of robotic arms, and path planning, and gradually the focus of researchers has shifted to algorithms that use statistical methods to analyze the input data. The data is categorized into a variety of features, and by identifying these features, the algorithm extracts the most useful ones and outputs them [81]. A hyper-redundant manipulator (HRM) has an extremely high degree of freedom, and an ellipsoid-shape rapidly-expanding random tree (E- RRT*) constrains the unwanted angles of the HRM and enhances the path planning [82]. Zhang Zhuo combines the APF method and proposes an improved RRT algorithm for path planning to achieve trajectory optimization and to ensure the safe, smooth, and fast movements of the robotic arm [83]. The improved RRT algorithm successfully enables the robotic arm to achieve obstacle avoidance. Bing Tong Li uses RRT-CC to solve the problem of obstacle avoidance for the 7-degree-of-freedom redundant robotic arm. Bing Tong Li used the RRT-Connect algorithm on the 7-degree-of-freedom redundant robotic arm obstacle avoidance problem and proved that the result is better than the RRT algorithm [84]. Jun Dai presented a novel potential-guided bidirectional fast exploration of random tree stars for redundant robot controllers with a direct connection strategy. A connection strategy for redundant robot manipulators in the joint space is proposed, designing a joint space expansion strategy based on artificial potential field and combining it with the GB-RRT algorithm to improve the obstacle avoidance ability; and designing a direct connection strategy to improve the expansion efficiency. Compared with bidirectional RRT and GB-RRT, it has better path planning [85]. Javier Moreno-Valenzuela proposes an adaptive gravity compensation proportional-derivative (PD) plus LIAW algorithm, which limits the angle of the robot arm to improve performance [86].

5. Discussion and Predictions

This paper introduces the research progress of robotic arms for humanoid robots, first consider musculoskeletal robots, but the modeling of skeleton is challenging, the number of bone joints, stiffness will affect the final performance, in addition to this also have to consider the rotational degrees of freedom, increase the rotational angle of the key nodes weight, reduce the weight of the optional nodes, the increase in the number of skeleton is not very friendly to the muscles attached to it, the high degree of freedom does can improve the range of motion and ability, but the algorithmic requirements are multiplied [87]. The current research on humanoid robots is more about the foot, and the research on the upper limb is not sufficient, because the research on the upper limb is generally based on the stabilization of the lower limb, however, the swing of the upper limb will inevitably affect the stabilization of the lower part of the body. Research has shown the importance of passive dynamics and chaos theory for walking robots, and this theory is also worth studying for the upper limb. The application of machine learning is also a growing trend, for the last 3 years most researchers have used machine learning and deep learning to help with research, or mimicry to make humanoid robots mimic human movement.

6. Conclusion

Using bibliometric analysis, this work offers a thorough overview of the development of humanoid robot robotic arms research. Humanoid robotic arm research has been expanding quickly in recent years, and the body of literature in this field has also been growing—especially after 2020, when it will rise exponentially. According to a review of highly referenced journals, the leading conferences and journals supported by IEEE have a big impact on this sector. About 2015 is when the number of citations to literature peaks. The mechanical design, control algorithms, and humanoid interface research hotspots are reflected in the keyword analysis. To advance the field, highly productive writers are starting to organize cooperative circles. Aspects of robotic arm system design optimization, motion control optimization, motion planning algorithms, simulation techniques, and sensor technologies are all explored in this research. The evolution of biomimicry, flexibility, high degrees of freedom, intelligent motion control, and human-robot collaboration is demonstrated by the study trend. The groundwork for the development of a fully humanized robot has been laid by the significant advancements made in the study of humanoid robot arms. Future studies should concentrate on important shared technological issues and encourage innovative theory and practice that work together.

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