Journal of Robotics and Control (JRC)
Volume 5, Issue 3, 2024
ISSN: 2715-5072, DOI: 10.18196/jrc.v5i3.21686

Controlling Robots Using Gaze Estimation: A Systematic Bibliometric and Research Trend Analysis

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***Abstract*—The rapid progression of technology and robotics has brought about a transformative revolution in various fields. From industrial automation to healthcare and beyond, robots have become integral parts of our society, such as using them to move laparoscopic cameras. Eye-gaze-based control in robotics is a cutting-edge innovation, providing enhanced human–robot interaction and control. However, current research is in the underexplored area of gaze-based control for robotics. This paper presents a systematic bibliometric analysis review of controlling robots using gaze estimation. The aim is to provide a research map overview of the use of eye gaze to control robots by clustering application areas based on ISIC-UN and several data acquisition technologies. Over the past 10 years, the number of publications in this field has been relatively stable, averaging 21.5 papers per year, with minimal fluctuations in annual article counts (σ = 4.9). This differs from research on robotics, which grows by an average of 1376 papers per year. Research on using eye gaze for robot control in the last 10 years in the field of human health and social work has only resulted in 17 articles; transportation and storage resulted in 12 articles; professional, scientific, and technical activities resulted in eight articles; information and communication resulted in five articles; and education and art resulted in two articles. Data acquisition technology for eye gaze research, primarily using a commercial eye tracker. Thus, there is significant potential for future research through the utilization of gaze estimation in various fields, as mentioned above.**

Keywords*—*Gaze Estimation; Robot Control; Bibliometric Analysis; Human-Machine Collaboration.

I. Introduction

Globally, the ongoing COVID-19 pandemic has underscored the significance of automation and remote operation, especially in healthcare and manufacturing sectors [1]–[4]. The potential of gaze estimation technology, which allows robots to follow the gaze of operators, paves the way for hands-free, contactless control in settings where hygiene and physical distancing are paramount [5]–[6]. Furthermore, as the global population ages and the demand for assistive devices grows, gaze-based control holds great promise for improving the lives of individuals with limited physical mobility [7]–[9].

Integrating gaze estimation technology into robot control represents a significant stride in developing human–robot interaction and automation systems [10]–[12]. In this era of increasing technological advancement, robotics has progressively moved beyond traditional remote-control methods and towards more intuitive, efficient, and adaptable modes of operation [13]–[15]. The concept of "controlling robots using gaze estimation" has emerged as an exciting frontier within this transformative landscape.

Currently, robotic systems play a pivotal role in various fields, from healthcare and industrial automation to education and entertainment [16]–[21]. However, enhancing the interaction and control of these systems to align with our natural behaviors remains a challenge. The global need for intuitive, user-friendly control mechanisms becomes increasingly pressing as robotics integrates into our daily lives [22]–[24].

In the context of autonomous vehicles, a trend that has gained significant global attention in recent years, the use of gaze estimation for driver monitoring and control could be transformative for road safety [25]–[27]. With an increasing emphasis on reducing accidents and improving transportation efficiency, integrating gaze estimation into autonomous vehicle control systems could provide more robust and reliable results [28]–[30].

Over the last decade, publications on eye gaze for controlling robots have shown a relatively consistent trend, with an average of 21.5 papers per year. There was a slight variation in the number of annual articles, as evidenced by a standard deviation of 4.9. This stability contrasts the field of robotics research, which has an average annual growth of 1,376 papers.

Eye-gaze control in robotics holds immense potential and can provide a natural and intuitive interaction between humans and robots. This technology can be particularly beneficial for individuals with physical disabilities, enabling them to control robotic devices using only their eye movements. Furthermore, eye-gaze control can enhance human–robot collaboration in various sectors, including healthcare, manufacturing, and entertainment.

Despite its potential, eye-gaze control in robotics also has several limitations. The accuracy of eye-gaze tracking can be affected by numerous factors, such as lighting conditions, user fatigue, and calibration error [31]–[35]. Moreover, the technology may not work effectively for individuals with certain eye conditions. Additionally, the cost of high-quality eye-tracking systems can be prohibitive, limiting widespread adoption.

Using eye-gaze control in robotics raises several ethical considerations [36]–[40]. Privacy concerns are paramount, as eye-tracking data can reveal sensitive information about a user's health status, emotional state, and thought processes [41]–[43]. It is crucial to ensure that such data is collected, stored, and used while respecting user privacy and complying with relevant regulations [44]–[45]. Additionally, the potential for over-reliance on robotic assistance could affect user autonomy and skill development.

This systematic review paper reports a comprehensive investigation of the state of the art, current trends, and research gaps on controlling robots using gaze estimation. By meticulously examining existing literature and identifying seminal research, we aimed to provide a well-rounded perspective on the achievements and challenges in this field. By combining these valuable insights, these papers establish a groundwork for future research that will influence how we engage with and manage robots via gaze estimation technology.

This contribution provides a comprehensive perspective on using eye gaze to control robot movements, stimulating researchers to develop this field further. This will also drive advancements in intuitive human–machine collaboration and align with the theme of human-centered automation in Industry 5.0.

II. Research Design and Method

Literature review, often regarded as the cornerstone of academic research, plays a pivotal role in shaping the knowledge landscape in any field of study [46]–[48]. It is a comprehensive survey and critical analysis of the existing literature related to a particular research topic. This essential step in the research process is crucial for several reasons, each contributing significantly to the advancement of knowledge and the success of a research project [49]–[51].

In this study, we employed a seven-step approach to construct a literature review. Stages 1 to 3 involved searching the Scopus database and refining the available data. In stage 4, we utilized bibliometric and descriptive statistics to outline the content of the literature review. In stage 5, we focused on the topic of controlling robots using gaze estimation. Finally, in stages 6 and 7, we depicted the research landscape and outlined the potential areas for future research, as illustrated in Fig. 1. The database Scopus was accessed on Jan 19, 2024.

A. *Stage 1 – Defining Initial Searches*

Stage 1 began with determining the keywords for extraction from the Scopus database. The rules outlined in Table I provide a systematic approach for extracting relevant documents from a Scopus database. By selecting Scopus as the primary database for the study, we show a commitment to accessing high-quality, comprehensive, and reliable scholarly literature relevant to this field. This choice aligns with the standards of academic excellence and ensures the robustness of the findings derived from the data retrieved.

All rules were searched within "Article title, Abstract, and Keywords." The first rule search was "controlling OR control OR controlled." The second rule was to search "robot OR robotics OR robotic." The third rule search was "eye OR eyes," and the last rule search was "gaze," as shown in Table I.

TABLE I. Keywords Define to Search Documents

Rule	*Search within*	*Search documents*
1	Article title, Abstract, Keywords	"controlling" OR "control" OR "controlled"
2	Article title, Abstract, Keywords	"robot" OR "robotics" OR "robotic"
3	Article title, Abstract, Keywords	"eye" OR "eyes"
4	Article title, Abstract, Keywords	"gaze"

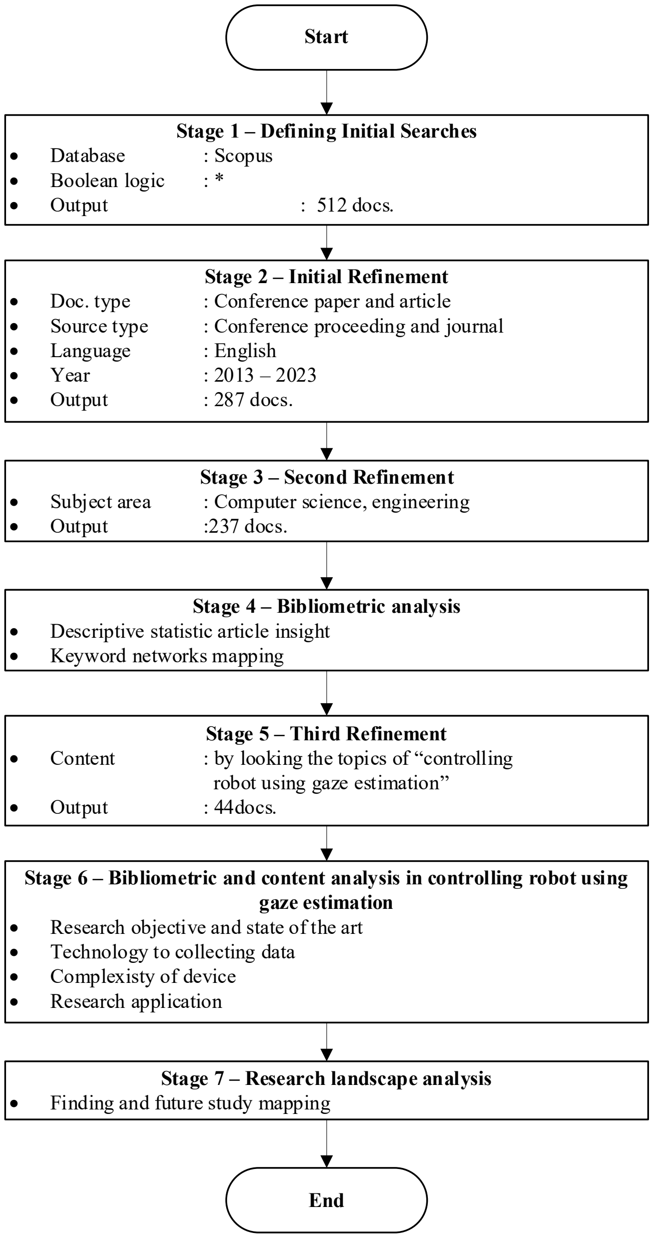


Fig. 1. Step to bibliometric analysis for controlling robot using gaze estimation

* (TITLE-ABS-KEY (controlling OR control OR controlled) AND TITLE-ABS-KEY (robot OR robotics OR robotic) AND TITLE-ABS-KEY (eye OR eyes) AND TITLE-ABS-KEY (gaze))

We employed a systematic approach using a combination of keywords to conduct the comprehensive search in the Scopus database. Rules 1 to 4 each were applied in conjunction with the others (Rule 1 AND Rule 2 AND Rule 3 AND Rule 4) in the search field.

We ensured that our search was all encompassing by selecting “All” for document type, which includes articles, conference papers, books, chapters of books, reviews, letters, notes, etc. We also chose “All years” for the years of publication and “All” for the access type to include both open-access and subscription-based resources.

Furthermore, we did not limit our search to any specific language or subject area. This meticulous and inclusive approach yielded 512 articles from 1989 to 2023. This method ensures a thorough review of available literature on the topic, providing a solid foundation for further research and study.

B. *Stage 2 – Initial Refinement*

From the initial pool of 512 articles, we found that many papers were categorized under multiple sections. To streamline our research, we refined our search parameters. We limited the document type to “articles” and “conference papers,” excluding books, book chapters, reviews, letters, notes, etc.

We also reduced the publication years to 2013–2023, and we focused on sources that were either “journals” or “conference proceedings” and restricted the language to “English.” This refined search strategy effectively sifted through the articles, leaving us with a more manageable 287 articles. This approach ensures that our research is focused and relevant while still being comprehensive.

C. *Stage 3 – Second Refinement*

During the second refinement stage, we focused our search on the subject areas of “Computer Science” and “Engineering.” This targeted approach led us to a collection of 237 articles. Of the 237 articles, 56% (132 documents) were conference proceedings, and 44% (105 documents) were journal articles. For details, see Fig. 2.

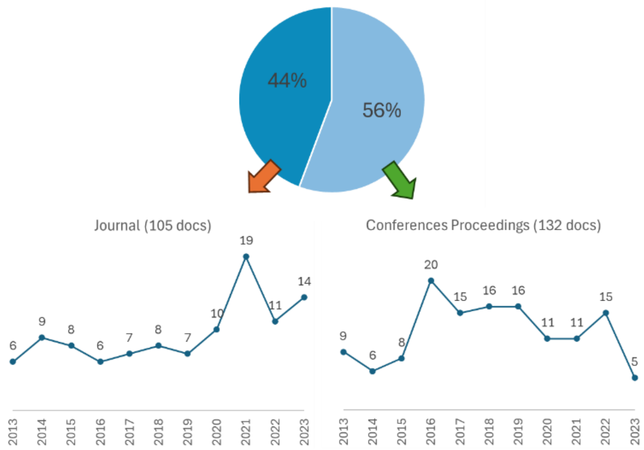


Fig. 2. Annual distribution based on source type

The progression from stages 1 to 3 is summarized in Table II. This method ensures that the articles selected for review are relevant and specific to our research interests, enhancing the precision and efficiency of our study.

TABLE II. STEP OF REFINEMENT

Stage	***Search Rule***	***Refine***	***Number of Article***
1	Rule 1 AND Rule 2 AND Rule 3 AND Rule 4	Doc. type: all Source type: all Language: all Year: 1989 - 2023	512
2	Rule 1 AND Rule 2 AND Rule 3 AND Rule 4	Doc. type: Conference paper and Article Source type: Conference proceeding and Journal. Language: English Year: 2013 - 2023	287
3	Rule 1 AND Rule 2 AND Rule 3 AND Rule 4	Subject area : Computer science, Engineering	237

III. BIBLIOMETRIC ANALYSIS

Bibliometric analysis is a statistical method used in academic research to study publishing trends and highlight relationships between published works [52]–[54]. It is advantageous in library and information science [55]–[56]. The key concepts in bibliometrics include relational and evaluative bibliometrics, which involve understanding the relationships between different publications and assessing their impact, respectively [57]–[58].

Bibliometric analysis can help answer various questions, such as finding collaborators for a study and determining how often articles from a particular field draw on studies from another field [59]–[60]. Bibliometric analysis allows researchers to identify emerging trends by analyzing the frequency of keywords, topics, or concepts appearing in the academic literature over time. Moreover, it is an indispensable tool for mapping the state of the art in each area of scientific knowledge and identifying essential information for various purposes, such as prospecting research opportunities [61]–[63].

A. *Descriptive Statistics of Articles*

Paper publications from 2013 to 2023 have generally been stable, averaging between 21 and 22 papers per year. A statistical analysis of the publications on this theme shows a standard deviation of 4.9, indicating that the fluctuation in publications has been minimal. The minimum, maximum, and quartile values of research from 2013 to 2023 are shown in Fig. 3. This is in contrast to research on robotics, which has grown by an average of 1376 papers per year.

Table III shows the 14 journals and conference proceedings that published three or more papers from 2013 to 2023. The *IEEE International Conference on Robotics and Automation Proceedings* has published the highest number, with nine documents in the last 10 years. Regarding the journal publication type, *Sensors* has published the most, with eight documents.

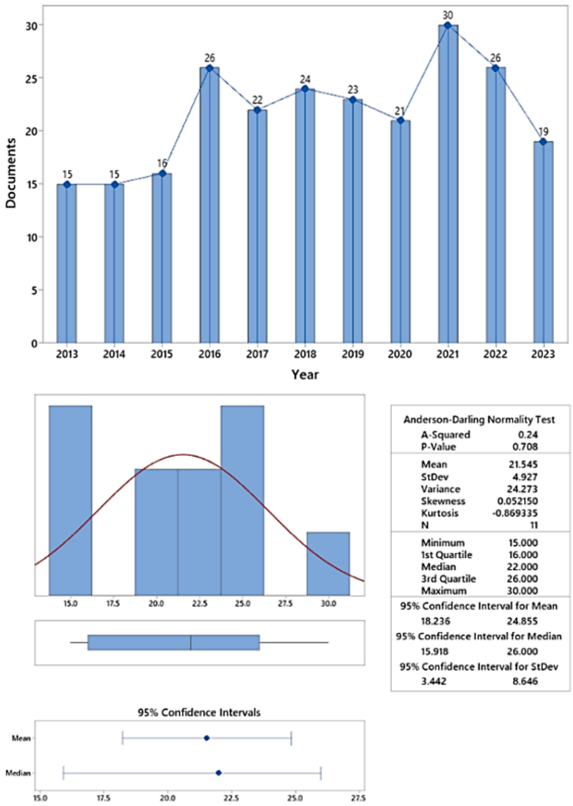


Fig. 3. Summary Report for Paper Production 2013 until 2023

B. Top 10 Most Cited Articles

Table IV lists the top ten articles that received the highest number of citations between 2013 and 2023. During the specified period, the article that received the most citations was written by Borji and Itti in 2013, focusing on a literature review of visual attention modeling. This paper was cited 1454 times over a decade, averaging 145.4 citations annually.

The subsequent most frequently cited work was by Ma et al. (2015), which discussed using electrooculography (EOG) and electroencephalography (EEG) data for robot control. Ma et al. (2015) garnered 166 citations over 8 years, resulting in an average of 20.75 per year. The third most cited paper was by Chen et al. in 2018, which detailed the control of a 7-DOF arm robot using EEG. Chen et al. (2018) received 115 citations over five years, averaging 23 citations per year.

C. Keyword Visualization Analysis

We used the VOSviewer software to illustrate the mapping of the author's keywords using the full counting method. We limited the minimum number of keyword occurrences to five to avoid complicated network visualization. With this parameter, we obtained the top 18 keywords with occurrences ranging from 5 to 46. As shown in Fig. 4 and Fig. 5, "eye tracking" and "human–robot interaction" emerged as the most frequently appearing keywords. The keyword "eye tracking" had 46 occurrences and a total link strength of 57. The keyword "human–robot interaction" had 44 occurrences and a total link strength of 62. Both also had a strong correlation. Meanwhile, other keywords, such as "gaze control," "eye gaze," and "gaze tracking" did not have a dominant presence.

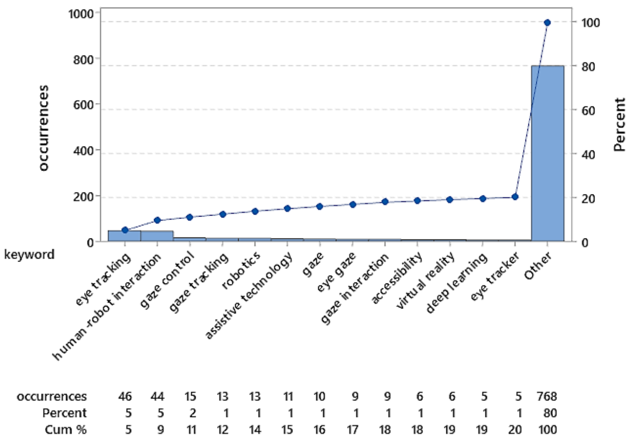


Fig. 4. Pareto chart of author's keywords

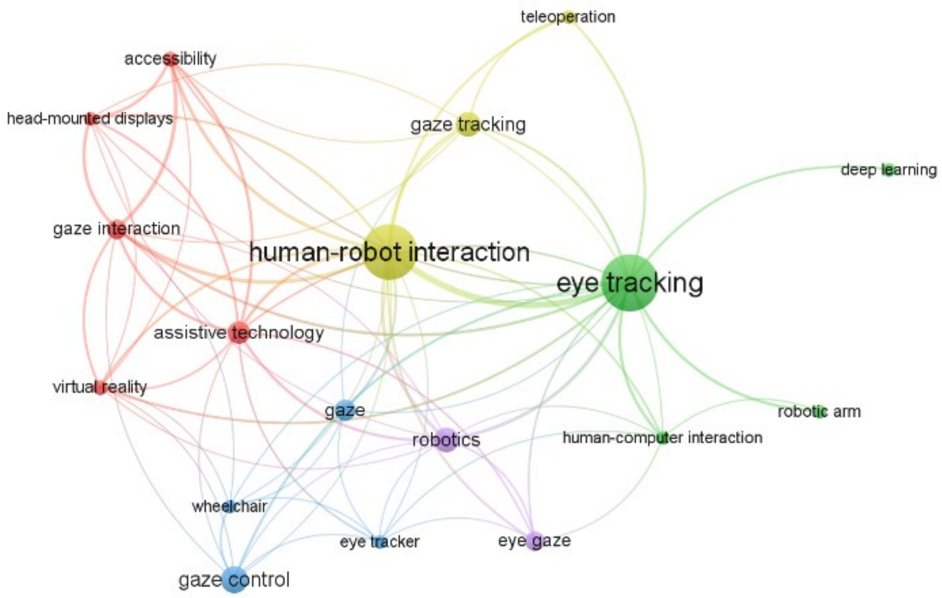


Fig. 5. Mapping of author's keywords

TABLE III. JOURNALS AND CONFERENCE PROCEEDINGS THAT HAVE PUBLISHED 3 OR MORE PAPERS FROM 2013 TO 2023

No.	*Source Title*	*Doc. Qty.*	*H-Index*	*Publication type*	*Country*	*Publisher*	*SJR Index*	*SJR Year*	*Cites/ doc*	*Index*
1	IEEE International Conference on Intelligent Robots and Systems	15	139	CP	United States	Institute of Electrical and Electronics Engineers Inc.	0.853	2022	3.17	
2	Proceedings IEEE International Conference on Robotics and Automation	9	207	CP	United States	Institute of Electrical and Electronics Engineers Inc.	1.186	2022	4.305	
3	Eye Tracking Research and Applications Symposium ETRA	8	54	CP	United States	-	0.196	2020	2.161	
4	Sensors	8	219	J	Switzerland	Multidisciplinary Digital Publishing Institute (MDPI)	0.764	2022	4.738	Q2
5	IEEE Transactions on Neural Systems and Rehabilitation Engineering	7	155	J	United States	Institute of Electrical and Electronics Engineers Inc.	1.26	2022	5.92	Q1
6	Frontiers In Neurorobotics	7	44	J	Switzerland	Frontiers Media S.A.	0.757	2022	3.865	Q2
7	ACM IEEE International Conference on Human Robot Interaction	5	62	CP	United States		0.498	2020	2.671	
8	Proceedings Of the IEEE Ras And EMBS International Conference on Biomedical Robotics and Biomechatronics	4	33	CP	United States		0.264	2020	1.372	
9	IEEE Robotics and Automation Letters	4	82	J	United States	Institute of Electrical and Electronics Engineers Inc.	1.693	2022	6.546	Q1
10	Proceedings Of the Annual International Conference of The IEEE Engineering In Medicine And Biology Society EMBS	3	39	CP	United States		0.216	2011	0.876	
11	IEEE Transactions on Cognitive and Developmental Systems	3	49	J	United States	Institute of Electrical and Electronics Engineers Inc.	1.173	2022	4.951	Q1
12	IEEE Access	3	204	J	United States	Institute of Electrical and Electronics Engineers Inc.	0.926	2022	5.178	Q1
13	Autonomous Robots	3	123	J	Netherlands	Springer Netherlands	1.165	2022	4.864	Q1
14	ACM International Conference Proceeding Series	3	137	CP	United States	Association for Computing Machinery (ACM)	0.209	2022	0.612	
Note : CP = Conference and Proceedings ; J = Journal										

TABLE IV. TOP 10 MOST CITED ARTICLES

Rank	*Author*	*Cited by*	*Title*	*Year*	*Source title*	*Keywords*
1	[64]	1454	State-of-the-art in visual attention modeling	2013	IEEE Transactions on Pattern Analysis and Machine Intelligence	bottom-up attention; eye movements; gaze control; gist; regions of interest; saliency; scene interpretation; top-down attention; Visual attention; visual search
2	[65]	166	A novel EOG/EEG hybrid human-machine interface adopting eye movements and ERPs: Application to robot control	2015	IEEE Transactions on Biomedical Engineering	Electroencephalogram (EEG); Electrooculogram (EOG); event-related potential (ERP); human-machine interface (HMI); robot control
3	[66]	115	Control of a 7-DOF Robotic Arm System with an SSVEP-Based BCI	2018	International Journal of Neural Systems	Brain-computer interface; electroencephalogram; robotic arm control; steady-state visual evoked potential
4	[67]	84	Combination of high-frequency SSVEP-based BCI and computer vision for controlling a robotic arm	2019	Journal of Neural Engineering	brain-computer interface (BCI); computer vision; electroencephalography (EEG); robotic arm; steady-state visual evoked potential (SSVEP)
5	[68]	72	The use of gaze to control drones	2014	Eye Tracking Research and Applications Symposium (ETRA)	Augmented or mixed reality systems; Drones; Gaze input; Gaze interaction; Head-mounted displays; Mobility; Multimodality; Robotics; UAV; Video gaming
6	[69]	64	Designing and evaluating a social gaze-control system for a humanoid robot	2014	IEEE Transactions on Human-Machine Systems	Active vision; context-dependent social gaze behavior; human-robot interaction; scene analysis; social attention
7	[70]	51	Predicting user intent through eye gaze for shared autonomy	2016	AAAI Fall Symposium - Technical Report	
8	[71]	51	Eye-Hand Behavior in Human-Robot Shared Manipulation	2018	ACM/IEEE	Eye gaze; Eye tracking; Human-robot interaction; Nonverbal communication; Shared autonomy
9	[72]	50	Gaze gesture based human robot interaction for laparoscopic surgery	2018	Medical Image Analysis	Eye-tracking; Gaze gestures; Gaze-contingent control; Minimally invasive surgery; Online calibration; Robotic surgery
10	[73]	48	Closed-loop hybrid Gaze Brain-machine interface based robotic arm control with augmented reality feedback	2017	Frontiers in Neurorobotics	Augmented reality feedback; Brain-machine interface (BMI); Closed-loop control; Eye tracking; Human-robot interaction; Hybrid Gaze-BMI

D. Scimago Journal Rank

Scimago Journal Rank (SJR) is a bibliometric indicator that measures the prestige or influence of an article in scientific journals. It is calculated based on the average number of citations per article or those published in a journal over the last three years. SJR is used to compare and assess scientific journals based on the impact of citations received by published articles. Higher SJR values indicate a more significant influence of the journal within the scholarly community.

SJR is calculated using the Scopus database (Elsevier) and considers the following factors: 1) journal coverage - the number of journals covered in Scopus; 2) the relationship between primary output and total output - the ratio of primary output (citable items) to total output per journal in the database; 3) assignment criteria for document types - how document types (articles, reviews, editorials, etc.) are accounted for; 4) accuracy of linkage between references and source data - the extent to which article references are linked to source records.

The journal with the highest SJR value was *IEEE Transactions on Neural Systems and Rehabilitation Engineering,* with an SJR value of 1.26. From the proceedings with an SJR value of 1.186, we obtained the *Proceedings IEEE International Conference on Robotics and Automation*. These journals and proceedings originate from the United States and are published by the Institute of Electrical and Electronics Engineers, Inc. (see Table III).

IV. Third Refinement by Studying the Topic of Controlling Robots Using Gaze Estimation

Some papers do not indicate using eye-gaze data to control a robot's movements. Even among the ten most-cited papers, some studies only utilized brainwave data to control robots. Therefore, based on mapping the author's keywords, we screened the 237 documents by searching for the research objective. The screening was performed by reading the abstract, keywords, and conclusion sections. Our screening process yielded eight distinct research clusters (see Fig. 6).

With 18 articles, Cluster One primarily included a focus on user attention and user interface log data, mainly modeling user interfaces for eye movement analysis. Cluster Two, containing 26 articles, included the application of robot avatars in Metaverse and virtual classrooms, with some articles exploring the integration of VR with eye movement.

With 33 articles, Cluster Three included various topics, including bio-robotic manipulation tasks, GPS navigation, fuzzy human gaze, robot collaboration, and multi-robot interactions. Cluster Four, encompassing 35 articles, included developing robot gaze models to enhance the naturalness of their interactions.

Cluster Five, consisting of 36 articles, included the interaction between humans and social or humanoid robots via ocular communication. Cluster Six, comprising 37 articles, included the application of eye trackers in ergonomic research. Cluster Seven included robot control through gaze estimation, and Cluster Eight included others.

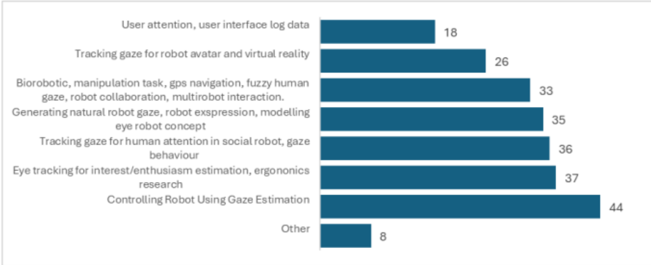


Fig. 6. 3rd refining research mapping

V. Bibliometric and Content Analysis of Controlling Robots Using Gaze Estimation

This section describes a more in-depth content analysis of 44 articles that discussed controlling robots using gaze estimation. The research articles' fields were arranged following the International Standard Industrial Classification (ISIC) of All Economic Activities industrial categorization, which is segmented into 21 sections per the United Nations' 2008 guidelines [74]. The distribution of these articles across various industry categories is provided in Table V.

TABLE V. Number of Articles Field Arrangements by ISIC

Section	*Description*	*Number of Article*
A	Agriculture, forestry, and fishing	-
B	Mining and quarrying	-
C	Manufacturing	-
D	Electricity, gas, steam, and air conditioning supply	-
E	Water supply; sewerage, waste management and remediation activities	-
F	Construction	-
G	Wholesale and retail trade; repair of motor vehicles and motorcycles	-
H	Transportation and storage	12
I	Accommodation and food service activities	-
J	Information and communication	5
K	Financial and insurance activities	-
L	Real estate activities	-
M	Professional, scientific, and technical activities	8
N	Administrative and support service activities	-
O	Public administration and defense; compulsory social security	-
P	Education	1
Q	Human health and social work activities	17
R	Arts, entertainment, and recreation	1
S	Other service activities	-
T	Activities of households as employers; undifferentiated goods- and services producing activities of households for own use	-
U	Activities of extraterritorial organizations and bodies	-

The human health and social work activities sector has the highest number of articles, with 17 papers making up 39%. This is followed by the transportation and storage sector, which contributes 12 articles or 27% to the total. The professional, scientific, and technical activities sector is represented by eight articles or 18%, while the information and communication sector comprises five articles or 11%.

Finally, the sectors of education and arts, entertainment, and recreation are each represented by a single article.

A. Human Health and Social Work Activities

There are 17 articles on using robots in the human health sector. All these articles can be reclassified based on the object of study being investigated, as shown in Fig. 7.

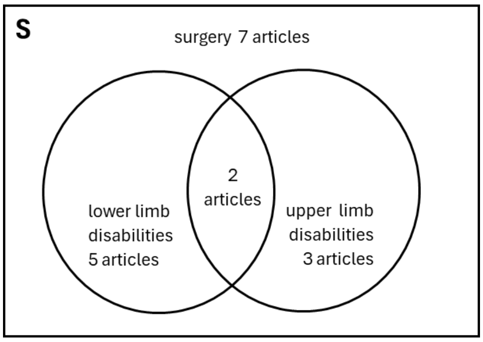


Fig. 7. Venn diagram based on the object of study in human health

Human health and social work activities (surgical robots). Seven articles have reported the application of gaze control to surgical robots. The first article presents a new robotic system for guiding needles during percutaneous procedures, focusing on its clinical application. The system uses a virtual platform based on the robot operating system (ROS) to position the needle. A control framework that tracks eye gaze was developed, allowing the clinician to control the robot and position the needle as desired. This means that the clinician can direct the robot's puncture sheath to reach the target simply by using their eye gaze [75].

The second article presents a design for an eye-tracking algorithm that can be utilized to operate surgical robots. The user can determine the surgical robot's movement direction or location through an eye-gazing technique [76]. The third article presents a new, more user-friendly, and ergonomic platform compatible with any flexible endoscope, facilitating smoother navigation and manipulation. A conventional endoscope was equipped with robotic features, and a gaze control system based on eye tracking was designed and implemented, enabling manipulation without using the hands [77].

The fourth article describes a robotic system where a surgeon's eye movements control a rigid endoscope held by a robotic arm, eliminating the need for a camera assistant. The system uses a series of eye movements, known as gaze gestures, to understand and execute the surgeon's intent for camera control [72]. The fifth article introduces a cost-effective and reliable deep-learning-based gaze estimator for the operation of surgical robots. This system allows physicians to effortlessly guide the robot by determining its initial and final points on a path using their gaze. Furthermore, the eye-gaze data from the controllers can be used to maneuver the surgical robots in nine different directions [78].

The sixth article discusses wearable eye-tracking technology combined with advanced computer vision techniques, such as Simultaneous Localization and Mapping (SLAM), to enhance surgical outcomes and patient safety. The system allows for the movement of a robotic laser via tracking of eye gaze and head position [79]. The seventh article introduces a system that enables surgeons to manipulate a robot using an interface controlled by eye-tracking glasses [80]. A list of research descriptions of the seven articles in the surgery field is shown in Table VI.

TABLE VI. RESUME OF RESEARCH DESCRIPTION IN SURGERY FIELD

Author's	*Data Acquisition Method*	*Research description (State of The Art-Theme-Objective)*
[75]	RGB Camera	Moving the biopsy needle with eye gaze (up, down, left, right, and middle) with an accuracy rate of 77.5 - 99.5% using CNN method to estimate eye gaze.
[76]	RGB Camera	Control the movement of the laparoscopic robot with eye gaze (point to point and up-down-left-right), accuracy 77-90% using CNN method to estimate eye gaze.
[77]	Eye tracker commercial	Operating an endoscopy robot using eye gaze. The success rate of locating the target by hand control is 90%, while by gaze control it is 100%. The average time to locate the target by hand control is 15 seconds, and by gaze control it is 8 seconds.
[72]	Eye tracker commercial	Moving the laparoscopic camera with eye gaze, error after calibration is 1.8mm, error after use is 9.4mm. Accuracy is 97.22 for 4 directions of movement.
[78]	Webcam	Using a webcam camera to estimate eye gaze with 9 directions of movement. The CNN method is used with an accuracy of 80-90%.
[79]	Eye tracker commercial + RGB Camera	Operating a surgery robot using eye gaze (eye tracker) and head position (RGB camera). The median error is 3.98cm with a 1.98 second delay.
[80]	Eye tracker commercial	The concept of surgical robot control with eye tracking

Human health and social work activities (lower limb disabilities). Five studies have applied gaze control to help lower limb disabilities. This involves information about the development of wheelchair control using eye gaze. The first article presents how a low-cost electric wheelchair available on the market was adapted to create a wheelchair that can be operated by the user's gaze. The proposed user interface allows the gaze-driven electric wheelchair to be used outdoors and controlled with an inbuilt joystick. A 360° camera enhances obstacle visibility and enables environmental safety checks without the need to physically turn the wheelchair [81]. The second article discusses the potential of interfaces controlled by eye movement. It describes a virtual reality (VR) driving experiment simulating wheelchair control [82].

The third article presents a Display/Eye Tracker device Set (DETS) introduced as an intelligent user interface that utilizes eye-gaze tracking. DETS is designed to be highly adaptable to meet the unique and specific requirements of each wheelchair user [83].

The fourth article presents integrated eye-tracking and gaze-contingent intention decoding with context-aware computer vision algorithms and autonomous navigation techniques used in self-driving vehicles. This allows paralyzed users to control the vehicle with their eyes. The system decodes the user's natural gaze to determine their intended destination [84].

The fifth article introduces an affordable, real-time method that allows individuals with disabilities to control their wheelchairs independently with eye movements. The method involves capturing images of the eye's movements using a webcam temporarily attached to a cap. For convenience and comfort, the camera is mounted on the wheelchair's arm. The eye movement images were processed in MATLAB using the Viola–Jones algorithm [85]. A list of research descriptions of the five articles in the field of lower limb disabilities is shown in Table VII.

TABLE VII. RESUME OF RESEARCH DESCRIPTION IN LOWER LIMB DISABILITIES FIELD

Author's	***Data Acquisition Method***	***Research description (State of The Art-Theme-Objective)***
[81]	Eye tracker commercial and camera 360	The wheelchair is attached with a laptop, eye tracker, and 360-degree camera, for movement control using eye gaze. The performance evaluation shows that joystick control is faster by 12-14 seconds in completing the test route than control with gaze.
[82]	Eye tracker commercial	Using eye gaze for wheelchair movement control. There are 3 points for turning left, going straight, and turning right. The interface can use VR and a computer screen.
[83]	Eye tracker commercial and RGB camera	Designing a wheelchair that can be controlled with gaze, to select destinations and equipped with an RGB camera to see obstacles.
[84]	Eye tracker commercial, RGB camera and Lidar	Combining eye-tracking integration and gaze-dependent intention interpretation with context-sensitive computer vision algorithms, along with the self-navigating methods utilized in autonomous wheelchair.
[85]	Webcam	Suggesting a wheelchair control system using eye movement, captured by a webcam and processed with MATLAB.

Human health and social work activities (upper limb disabilities). Three articles describe gaze control to help with upper limb disabilities. This includes information about the development of arm robot control using eye gaze. The first article presents a robot to assist patients with hand mobility disorders. The robot is operated using eye gaze to help patients pick up food. This study demonstrates how the use of gaze can improve assistance algorithms. The behavior of eye gaze during the teleoperation of robot manipulation and juxtaposed their observations with those from existing literature on manual manipulation [71].

The second article introduces a robotic arm, guided by eye gaze, designed to assist in rehabilitating individuals with severe motor and speech impairments [86]. The third article proposes that integrating artificial stereovision and eye-tracking technology is a viable approach, mainly as a person's vision is often unaffected by their upper limb disability. This research involved creating a preliminary model (concept) for operating an assistive robotic arm using an affordable combination of stereovision and eye-tracking systems [87]. A list of the research descriptions of the three articles in the field of upper limb disabilities is shown in Table VIII.

TABLE VIII. RESUME OF RESEARCH DESCRIPTION IN UPPER LIMB DISABILITIES FIELD

Author's	***Data Acquisition Method***	***Research description (State of The Art-Theme-Objective)***
[71]	Eye tracker commercial	The concept of human-robot collaboration involves creating systems that leverage the advantages of autonomous robot behaviors to assist patients with hand paralysis. This is done by enabling them to use a robotic arm, controlled by their eye gaze, to pick up food.
[86]	Eye tracker commercial	Helping the disabled with pick and drop activities using object detection and selection with eye gaze. An experiment with 2 shuttlecocks selected and moved. Tested on 9 disabled people and 9 normal people.
[87]	Eye tracker commercial and stereo vision	Robotic arms designed for assistance enable individuals with disabilities in their upper limbs to perform everyday tasks, such as grasping objects and drinking, independently. successfully reaching and grasping an object for 92%

Human health and social work activities (upper and lower limb disabilities). Two studies applied gaze control to help people with upper and lower limb disabilities. The first article presents using eye gaze to control a telerobot. This is intended for people with paralysis of the hands and feet [88].

The second article reports an experimental analysis comparing telepresence robots controlled by gaze and hands using a head-mounted display. The participants (n = 16) reported similar levels of presence and self-assessment. However, the gaze control method was 31% slower than the hand control method [89]. A list of the research descriptions of the two articles in the field of upper and lower limb disabilities is shown in Table IX.

TABLE IX. RESUME OF RESEARCH DESCRIPTION IN UPPER AND LOWER LIMB DISABILITIES FIELD

Author's	***Data Acquisition Method***	***Research description (State of The Art-Theme-Objective)***
[88]	Eye tracker commercial	concept of several design robots with eye gaze as a UI for people with disabilities.
[89]	VR eye tracker commercial	Control the telerobot with eye gaze (right, left, straight) for upper and lower limb disabilities. Compare control with joystick and with eye. Hand = 86% Gaze = 85%

B. Transportation and Storage

There are 12 articles on using robots in the transportation and storage sector. Fig. 8 shows the percentage of controlled robots by type. The largest category is robotic arms, which account for 75% (9 articles) of all controlled robots. The second largest category is vehicles, which account for 16.7% (2 articles) of all controlled robots. The remaining 8.3% include controlled drones.

Transportation and storage (controlling arm robots). Nine articles discuss using eye gaze to control arm robots. The first article presents a two-camera eye-tracking system (TCES) that can record eye movements, recognize objects, and be applied to controlling robotic arms. This study used machine learning to train a convolutional neural network to detect eye directions from a webcam and the pupil center-corneal reflection (PCCR) method to track gaze with a commercial eye tracker. The eye-gaze patterns are used to control the robot arm. The patterns include eyes up (start moving the arm), blinking (stopping the action), left (grab an object), and right (release an object). This paper claims that, in trials with these conditions, it has an accuracy of up to 99.99% [90].

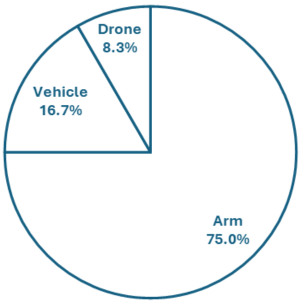


Fig. 8. Grouping based on controlled robot

The second article presents an EMG-based gaze estimation and camera image processing system to control a robot arm to grasp objects with high precision. The user selects camera images and moves the robot arm through the selected images to manipulate the robot arm. The EMG gaze estimation identifies the object the robot arm should grasp [91]. The third article proposes a lightweight head-mounted interface for robust and real-time robot control, weighing only 162 g (see Fig. 9). The interface combines a head-mounted eye tracker (number 4), an RGB-depth camera (number 3), and a custom magnetic angular rate gravity (MARG) sensor board (number 1) to calculate the user's head pose and a 3D gaze point, which is used as the input target point for the robotic end effector in Cartesian coordinate space. Number 2 is a feedback laser. [92].

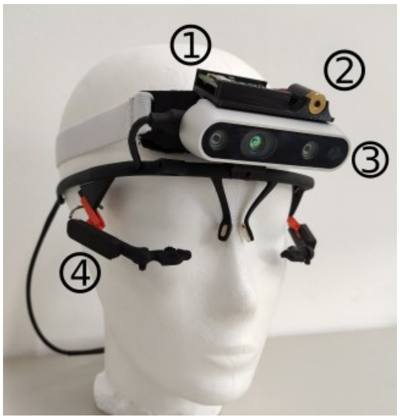


Fig. 9. Proposed lightweight head-mounted interface [92]

The fourth article presents a forward-thinking specializing in supernumerary robotic limbs (SRL), adept at expanding human physical capabilities in diverse environments. Developing innovative solutions, including a gaze information-based control system for SRL, demonstrating precise control with an average error of 26 mm/m. The article shows proven in acquiring and transforming gaze and environmental information and thus optimizing SRL operation efficiency.

Fig. 10 shows the operator, adept at sequentially targeting positions 1, 2, and 3, utilizing eye-tracking technology and depth sensors for precise gaze position and target distance measurements. It is proficient in transforming coordinates from the target into an inertial measurement unit (IMU) head, establishing a seamless connection to the IMU SRL coordinate system via an effective control system integration [93].

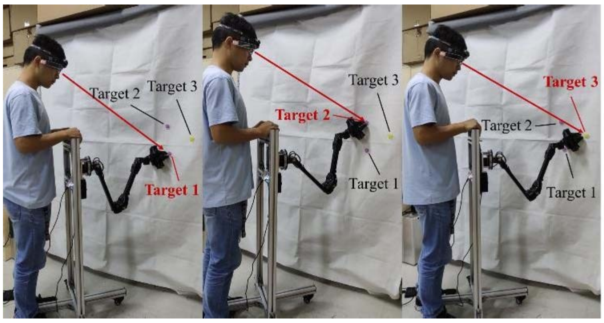


Fig. 10. SRL controlling by eye tracker, depth sensor and IMU [93]

The fifth article introduces a semi-autonomous robotic system designed to execute reach-and-grasp tasks. The focus is a novel control mechanism for a robotic arm during reaching tasks, incorporating dynamic blending of robot autonomy and gaze-based brain–machine interface (gaze-BMI) control from the user. The hybrid gaze-BMI is an intuitive and efficient input method, allowing users to seamlessly control the robotic arm's end-effector in a 2D workspace, with the movement speed adjustable in proportion to the user's intended strength. An experimental setup was implemented, as illustrated in Fig. 11 [94].

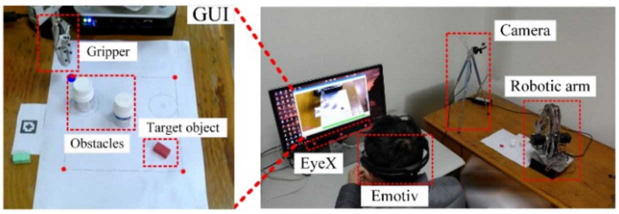


Fig. 11. Experiment setup for hybrid gaze-BMI [94]

The sixth article introduces and validates a framework for gaze-based interaction with assistive robots. It allows users to control a robot from a distance by directing their gaze to specify the object for manipulation. The experiments demonstrated the successful execution of commands, as users effectively guided an NAO robot to retrieve designated objects using their eye movements [95].

The seventh study developed and validated a gaze-based human-robot interaction (HRI) system utilizing 3D gaze in natural environments to command a robotic arm for complex tasks. A gaze vector method was implemented for accurate 3D gaze estimation, and a novel interaction framework mimicked human visuomotor functions, enhancing control capability in relatively complex robotic tasks. The experimental setup is shown in Fig. 12 [96].

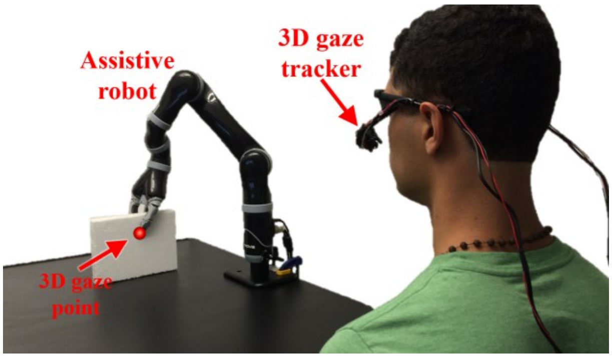


Fig. 12. Setting up an experiment involving the utilization of 3D gaze to direct an assistive robot in performing grasping actions [96]

The eighth article presents a combined brain–computer interface that merges gaze data from an eye tracker with EEG measurements of brain activity. Participants actively guide the robotic arm's end effector in one of four directions for executing a pick-and-place task [97]. The ninth article presents eye-gaze tracking and motion prediction to control arm robots. Eye tracking data estimates operator intention, allowing the robot to focus on that object [98]. A list of research descriptions of the eight articles in the field of transportation and storage (controlling arm robots) is shown in Table X.

Transportation and storage (controlling land vehicle robots). Two articles involved eye gaze to control vehicle robots. The first article introduces a hybrid gaze and brain–computer interface (BCI) to provide formation input to a multi-robot system (MRS). The operator uses the keyboard for system monitoring input and the hand controller for velocity control input. Fig. 13 [99] shows an overview of the experiment.

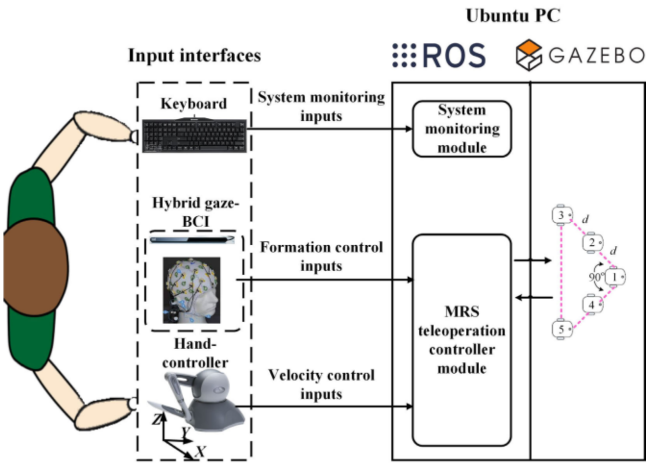


Fig. 13. Overview experiment of controlling MRS [99]

The second article suggested controlling mobile robots using vision-based gaze guidance. The focus of utilizing gaze interaction and wearable and mobile technology was primarily on overseeing robot movements. Users were allowed to operate the robot remotely and hands-free by directing it to the desired location via eye movements [100]. A list of the research descriptions of the two articles in the field of transportation and storage (controlling land vehicle robots) is shown in Table XI.

TABLE X. RESUME OF RESEARCH DESCRIPTION IN UPPER AND LOWER LIMB DISABILITIES FIELD

Author's	***Data Acquisition Method***	***Research description (State of The Art-Theme-Objective)***
[90]	Eye tracker commercial and webcam	The eye gaze patterns are used to control the robot arm. The patterns include eyes up (start moving the arm), blink (stop the action), left (grab an object), and right (release an object), accuracy of up to 99.99%
[91]	EOG and camera	Uses EMG-based gaze estimation and camera image processing to control a robot arm to grasp objects with high precision
[92]	Eye tracker commercial, RGB camera, MARG sensor	Eye tracker = gaze detection, RGB Camera = acquisition of environmental conditions, MARG sensor = head pose, accuracy EYE 2D = Euc total error 28 ± 28.5 mm EYE 3D = euc total error 27.4 ± 21.8mm 3D head gaze 19 ± 15.7mm
[93]	Eye tracker commercial, Depth sensor, and IMU	Control supernumerary robotic limbs by eye gaze, mean absolute error 2.6%
[94]	Eye tracker commercial and BMI	Combines brain waves and eye tracker for robot movement, accuracy 82.1 ± 4.8 %
[95]	Eye tracker commercial and kinect	Control hand moving NAO robot to take object at gaze mark. Activation time by gaze μ=2252ms SD=471ms; by mouse μ=2762ms SD=1100ms
[96]	Eye tracker commercial	Using 3D gaze tracker to determine gaze point as command robot for grasping, error 2.1±1.3 cm
[97]	Eye tracker commercial and EEG	Guide the arm robot by combine gaze data obtained from an eye tracker with brain activity information recorded through EEG
[98]	Eye tracker commercial, flexible sensor tube (FST), kinect, vision camera, stereo camera	The upper limb humanoid robot is controlled using an eye tracker to estimate operator intention, FST for estimating operator hand motion, Kinect RGB Depth sensor for determining object position and shape. Vision and stereo cameras are used as input for VR/AR.

TABLE XI. RESUME OF RESEARCH TRANSPORTATION AND STORAGE (CONTROLLING VEHICLE ROBOT)

Author's	***Data Acquisition Method***	***Research description (State of The Art-Theme-Objective)***
[99]	Eye tracker commercial, BCI-EEG, hand controller and keyboard	This article use of a hybrid gaze and brain-computer interface (BCI) to provide formation input to the multi-robot system (MRS), accuracy of the hybrid gaze-BCI (96.00±2.57%).
[100]	Eye tracker commercial	Controlling robot path trajectory using eye gaze.

Transportation and storage (controlling drones). Only one article involved an eye tracker to control a drone. The experiment involved controlling four drone flight parameters: speed, translation, rotation, and altitude. Two parameters were controlled using a keyboard, and the other two were controlled using eye gaze. Four control modes were implemented: Mode 1 involved translation and altitude controlled by gaze and rotation and speed controlled by the keyboard. Mode 2 included rotation and altitude controlled by gaze and translation, with speed controlled by the keyboard. Mode 3 consisted of translation and speed controlled by gaze, with rotation and altitude controlled by the keyboard. Mode 4 comprised rotation and speed controlled by gaze, with translation and altitude controlled by the keyboard, as shown in Fig. 14. The results of this experiment indicate that Mode 4 exhibited the best ease of control as it had the lowest error rate [68].

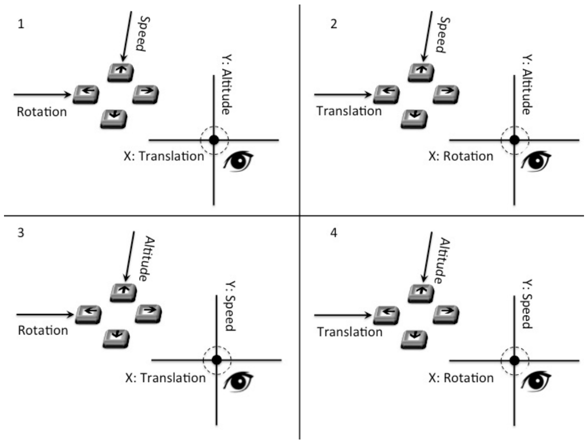


Fig. 14. Experiment mode of controlling drone by eye gaze and keyboard [68]

C. Professional, Scientific, and Technical Activities

Eight articles described eye gaze for professional, scientific, and technical activities. The first study created an innovative asynchronous control system for a robotic arm, integrating steady-state visual evoked potentials (SSVEP) and eye tracking within a virtual reality (VR) setting. It implemented simultaneous and sequential modes, with target classification achieved via the decision-level fusion of EEG with eye gaze. User autonomy was introduced by allowing subjects to initiate and halt the system using triple blink and eye closure while employing an adjustable window method for flexible stimulus duration [101].

The second article identified the most effective operating range for a particular screen-based eye-tracking device, the Tobii X2-30, concerning changes in both precision and accuracy in measurements. Regarding the optimal operational parameters for the Tobii X2-30 screen-based eye-tracker, various experiments indicated that the highest levels of accuracy and precision were achieved when the user was positioned at a y distance within the 55–65-cm range. Minimizing movement is advantageous, as centered alignment with the eye-tracker yields more accurate measurements than off-center positioning. However, a lateral shift of 5 cm in either direction along the x-axis did not adversely affect the results. The optimal z distance was found to be 52 cm [102].

The third article introduces a configuration for establishing a connection to control a collaborative robot (cobot) Omron TM5-700 using a Tobii Pro X2-30 eye tracker. The software application was developed using OMRON TMFlow and the Tobii software development kit (SDK). They created a practical demonstration and experimental configuration [103]. The fourth article presents a user-friendly command system that relies on eye tracking that can be integrated into telepresence robots. These robots are commonly utilized to facilitate distant social engagement and create a sense of being present [104].

The fifth article describes an innovative idea leading to a functional prototype that employed eye-tracking technology. The prototype could enhance visibility and communication for individuals in both professional and domestic settings. The idea involves a portable headset that monitors the user's gaze and precisely directs an illuminating source to the point where the eyes are focused [105].

The sixth study investigated how the intricate structure of a group of robots influences performance of a task involving interaction with humans. It explored whether these variations are evident in average neurophysiological and behavioral traits. Participants operated six ground robots using two different geometric arrangements to reach randomly appearing targets during the experiment [106].

The seventh article introduces an innovative human–machine interface (HMI) that combines EOG and EEG. The hybrid interface operates in two modes: the EOG mode identifies eye movements, such as blinks, while the EEG mode detects event-related potentials (ERPs), such as P300 [34]. The eighth study explored the relationship between EOG signals and eye movement displacement. It aimed to determine the most suitable geometric transformation to establish a connection with minimal error [107]. A list of research descriptions of the eight articles in the field of professional, scientific, and technical activities is shown in Table XII.

TABLE XII. RESUME OF RESEARCH DESCRIPTION IN AREA PROFESSIONAL, SCIENTIFIC, AND TECHNICAL ACTIVITIES

Author's	***Data Acquisition Method***	***Research description (State of The Art-Theme-Objective)***
[101]	Eye tracker commercial and EEG	Controls 8 basic virtual movements using brain frequencies. Eye tracker = blink detection, EEG = brain frequency. Accuration 90.5%
[102]	Eye tracker commercial	Search optimal distance parameter for Tobii X2-30. X=0±5cm Y=55-65cm Z=52cm
[103]	Eye tracker commercial	configuration for establishing a connection to control a collaborative robot (cobot) Omron TM5-700 using a Tobii Pro X2-30
[104]	VR eye tracker commercial	concept user-friendly command system relying on eye tracking can be integrated into telepresence robots.
[105]	Eye tracker commercial	Directing the laser towards the target based on gaze. The laser is mounted on the helmet.
[106]	Eye tracker commercial and EEG	Observing the relationship between neuropsychological aspects and eye gaze while observing the movement of a robot with two different configurations.
[65]	EOG and EEG	Use data EOG and EEG for humanoid robot controlling.
[107]	EOG	Find the optimum geometry transform for the relationship between EOG signals and eye movement displacement.

D. *Information and Communication*

Five articles involved eye gaze for information and communication activities. The first article describes how telepresence systems with mobile robots are becoming more commonly utilized to foster social engagement among individuals separated by distance. The focus was on exploring the application of gaze interaction in these robotic systems to create additional possibilities for individuals facing physical challenges [108]. The second article discusses designing a VR interface for telerobot control training using eye gaze. In this article, eye gaze determines the direction of a telerobot carrying a 360-degree camera [109]. The third article presents a telepresence robot's head and gaze control design with a 360-degree camera. In this study, in addition to using a VR eye tracker, an inertial measurement unit (IMU) was also employed to detect the direction of head movements [110].

The fourth article discusses the use of eye gaze to map the complexity of the workspace of an arm robot, detect objects, and partition scenarios. This is employed for performing hazardous tasks. This capability also allows operators to be far from the work area [111]. The fifth article presents the use of eye gaze to operate a telerobot. The robot was equipped with a Kinect 3D camera sensor to monitor its surroundings [112]. A list of the research descriptions of the five articles in the field of information and communication is shown in Table XIII.

TABLE XIII. RESUME OF RESEARCH IN AREA INFORMATION AND COMMUNICATION

Author's	***Data Acquisition Method***	***Research description (State of The Art-Theme-Objective)***
[108]	VR eye tracker commercial	The concept of moving a tele-robot that carries a 360-degree camera using eye gaze to direct the camera.
[109]	VR eye tracker commercial	Creating a VR eye gaze control simulation.
[110]	VR eye tracker commercial and IMU	Moving a tele-robot that carries a 360-degree camera using eye gaze and IMU (Inertial Measurement Unit).
[111]	Eye tracker commercial	use of eye gaze to map the complexity of the workspace of an arm robot, detect objects, and scenario partitioning.
[112]	Eye tracker commercial	use of eye gaze to operate a tele-robot that carries a Kinect 3D camera sensor.

E. *Education*

One study applies eye-gaze control to the field of education. This research explored the challenges children with physical impairments face in play due to limitations in reaching and handling objects. The study focused on testing two eye-gaze interfaces: an attentive user interface with a neural network for predicting target toys and an explicit eye-input interface that detects fixated toys.

The interfaces were evaluated in a whack-a-mole game to assess performance and advantages. While the explicit interface achieved 100% prediction accuracy, the attentive interface demonstrated an average 86.4% accuracy (see Fig. 15). A student operated the robotic system, and there was an illustration depicting the system setup and the associated activity. Participants were positioned behind the stand, observing through a hole to ensure that their eyes remained within the operational range of the eye tracker [113].

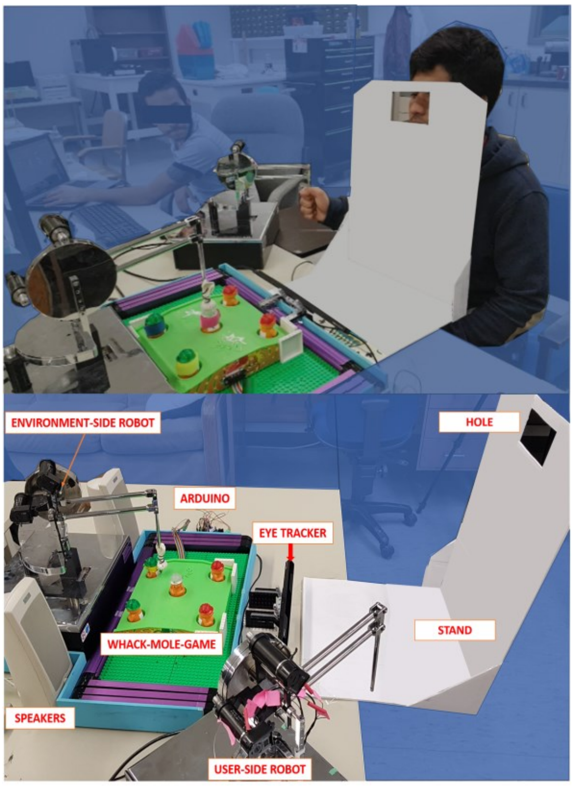


Fig. 15. experimental setup of whack-mole game [113]

F. *Arts, Entertainment and Recreation*

One study utilized eye gaze for entertainment purposes, specifically regarding the use of gaze to control a multimedia player. Eye gaze was detected using a webcam and processed using a neural network algorithm. This study explored the ability of eye gaze to control functions, such as play, pause, forward, and backward, on a multimedia player. Blinking was used as a signal for clicking/confirmation. The accuracy of this system depends on the lighting conditions on the user's face. Under daylight conditions, the accuracy was 93%. Under regular lighting conditions, the accuracy was 94%. Under controlled lighting conditions, the accuracy was 99%. However, if the lighting conditions involved screen light, the accuracy was only 9% [114].

To develop a study on the use of eye gaze for robot control, we suggest focusing on the following criteria.

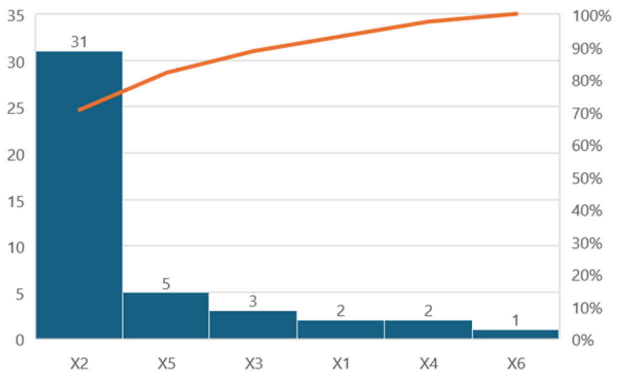
- Performance Evaluation: Comprehensive performance evaluation data increase the approach's credibility. This could include quantitative assessments of accuracy, responsiveness, and user satisfaction based on user studies or simulations.
- Usability and User Experience: Ease of setup, calibration, and user interface design are all critical considerations when using assistive technologies. Insights from user feedback or usability testing could improve the system and maximize the user experience.

- Long-Term Usability and Reliability: It is vital to assess the proposed method's long-term usability and reliability to ensure its usefulness in real-world situations. To improve the system's overall reliability and user acceptance, researchers should consider factors, such as resilience to external conditions, hardware component durability, and adaptability to diverse user needs.
- Integration with Existing Technologies: Investigating possible integrations with existing assistive technologies or platforms can increase the proposed method's usefulness and interoperability. Collaboration with essential stakeholders, such as healthcare professionals and assistive technology vendors, might enable the system's seamless integration and adoption within current ecosystems.

VI. Research Landscape

A. *Technology for Collecting Data*

Most eye-gaze estimation data have been obtained using commercial eye trackers, accounting for 36 articles or 81%. Specifically, 31 studies used commercial eye trackers as a single device, while five studies combined commercial eye trackers with EEG, as illustrated in Fig. 16. Some have used webcams to acquire eye-gaze data (three articles). Two studies utilized EOG data, and another two employed RGB camera sensors. Meanwhile, only one combined EOG with EEG data.



RGB Camera	X1
Eye tracker commercial	X2
Webcam	X3
EOG	X4
EEG & Eye tracker commercial	X5
EOG & EEG	X6

Fig. 16. Pareto sensor used to collect eye gaze data

B. *Document Type Map*

Of the 44 papers discussed, 55% (24 documents) were conference papers, and 45% (20 documents) were journal articles. Both conference papers and journal articles play essential roles in academic publication, communicating research findings and contributing to intellectual discourse. While they have commonalities in content and rigor, they also have differences, each with advantages and disadvantages.

The first advantage of conference papers is that they often provide a more rapid means of sharing research outcomes. Because conferences occur regularly, researchers can quickly present their findings to the academic community. Second, presenting a paper at a conference allows authors to receive immediate feedback from peers and experts. This interactive exchange can lead to valuable insights and suggestions for further refinement. Third, conferences offer networking opportunities, enabling researchers to establish connections with other professionals, potential collaborators, and funding agencies. Fourth, conferences cover a broad range of topics within a specific field or discipline, allowing researchers to engage with diverse perspectives and interdisciplinary approaches.

The first benefit of journal articles is that they usually go through a thorough peer review process by subject matter experts, guaranteeing high-caliber research and conformity to academic standards. Second, journals allow authors to explore in-depth research findings and include thorough analyses, comments, and interpretations. Third, published publications are frequently kept up to date in databases and repositories, which increases their visibility and accessibility for researchers worldwide. Fourth, compared to conference papers, journal articles typically obtain more citations, enhancing the authors' academic standing and advancing scientific knowledge.

C. *Practical Implications*

Using eye gaze to control robots presents many practical implications for stakeholders, including practitioners, policymakers, and other relevant parties.

Enhanced Accessibility and Usability: Integrating eye-gaze control into robots can significantly enhance accessibility for individuals with physical disabilities. This technology can empower people with limited mobility to interact with robots more intuitively and effectively, improving their quality of life. Researchers designing assistive technologies could leverage these findings to create solutions that are more inclusive.

Improved Human–Robot Interactions (HRIs): Understanding how humans naturally use their eye gaze to communicate can significantly enhance the design of robots for seamless interaction. By incorporating eye-gaze control, researchers can develop robots that respond more naturally to human cues, improving HRI experiences in various settings, such as healthcare, education, and customer service.

Safety and Efficiency in Industrial Settings: In industrial environments where robots often collaborate with human workers, precise and efficient control mechanisms are crucial. Eye-gaze control can enable operators to guide robots with greater accuracy and speed, improving overall productivity and safety. Policymakers and regulatory bodies can consider these findings when developing guidelines for integrating robots into industrial workplaces.

Privacy and Ethical Considerations: As eye-gaze technology advances, stakeholders must address privacy concerns related to data collection and user consent. Policymakers play a vital role in establishing regulations to safeguard individual privacy rights while ensuring the responsible use of eye-gaze data by robot manufacturers and developers.

Cross-disciplinary Collaboration: Given the multifaceted nature of integrating eye-gaze control into robots, collaboration among researchers from diverse fields, such as psychology, engineering, and computer science, becomes imperative. Policymakers can facilitate such collaborations by incentivizing interdisciplinary research initiatives and funding opportunities.

The practical implications of using eye gaze to control robots are vast and diverse, involving accessibility, human–robot interaction, safety, privacy, education, economics, and interdisciplinary collaboration. By considering these implications, stakeholders can enhance the relevance and impact of their endeavors in this rapidly evolving field.

D. Methodology Strengths and Weaknesses

The methodological strengths and weaknesses of prior studies on using eye gaze to control robots can provide valuable insights for guiding future research directions. Here is an overview of potential strengths and weaknesses.

Methodological strengths in experimental controls: Many existing studies employ controlled experimental settings, ensuring that variables other than eye gaze are minimized or controlled. This enhances the internal validity of the findings.

Quantitative data: Quantitative data allows for precise measurement and analysis of eye-gaze patterns, facilitating statistical inference and robust conclusions. Technological advances in eye-tracking technology have enabled more accurate and real-time tracking of eye movements, enhancing the reliability and validity of the data collected.

Cross-disciplinary approaches and studies often integrate knowledge from various fields, such as human-computer interaction, robotics, and cognitive psychology, leading to comprehensive insights and innovative methodologies.

Methodological weaknesses include small sample sizes. Many studies suffer from small sample sizes, limiting the generalizability of findings and statistical power. Future research should aim for larger and more diverse participant pools.

Limited contexts: Some studies have focused on specific tasks or contexts, which may not fully capture the complexity of real-world interactions with robots. Future research should explore a broader range of scenarios.

Measurement limitations: Despite advancements, eye-tracking technology still has limitations, such as accuracy issues, especially in dynamic environments or with specific user populations (e.g., individuals with disabilities). Improvements in technology are needed to address these challenges.

Ethical concerns regarding privacy, consent, and data security in eye-tracking research must be carefully addressed to ensure participant well-being and compliance with ethical guidelines.

User experience considerations: Some studies may overlook subjective user experiences, focusing solely on performance metrics. Future research should incorporate qualitative methods to explore user perceptions, preferences, and usability issues.

Addressing these strengths and weaknesses can guide future research directions in using eye gaze for controlling robots, ensuring methodological rigor and relevance to practical applications.

E. Research Map

This section provides a research map for controlling robots using gaze estimation. Articles on controlling eye gaze in the field of human health and social work activities included 17 articles or 49%. This field focuses primarily on surgical robots that move laparoscopic cameras according to eye gaze. A summary of the research field is presented in Table XIV.

TABLE XIV. RESUME OF RESEARCH FIELD

Data acquisition technology for eye gaze	**Research field**											**Σ**
	Q				***H***							
	QA	***QB***	***QC***	***QD***	***HA***	***HB***	***HC***	***M***	***J***	***P***	***R***	
RGB Camera	2											2
Eye tracker commercial	4	4	3	2	6	1	1	4	5	1		31
Webcam	1	1									1	3
EOG					1			1				2
EEG & Eye tracker commercial					2	1		2				5
EOG & EEG								1				1
Σ	7	5	3	2	9	2	1	8	5	1	1	44

Description		
Description	H	Transportation and storage
	J	Information and communication
	M	Professional, scientific, and technical activities
	P	Education
	Q	Human health and social work activities
	R	Arts, entertainment, and recreation
	QA	Surgical
	QB	Lower limb disabilities
	QC	Upper limb disabilities
	QD	Upper Lower limb disabilities
	HA	Arm robot
	HB	Land vehicle robot
	HC	Drone

VII. CONCLUSION AND FUTURE RESEARCH

This review described a systematic bibliometric analysis of publications from 2013 to 2023 on controlling robots using eye gaze. Over the past 10 years, publications in this field have been relatively stable, averaging 21.5 papers per year, with insignificant increases and decreases in articles per year, indicated by a standard deviation of 4.9. The lowest number of publications in the last 10 years occurred in 2013 and 2014, with 15 articles, while the highest was in 2021, with 30 articles. Proceedings still lead in terms of the type of article published in this field. Based on data analysis from the first to the third positions, the highest production by the publication type was "conferences and proceedings." Among the proceedings, most articles were published in the *IEEE International Conference on Intelligent Robots and Systems* by the Institute of Electrical and Electronics Engineers Inc., with 15 articles. Regarding journals, *Sensors* from the Multidisciplinary Digital Publishing Institute (MDPI) published the most articles (eight).

The paper provides a research map and future research opportunities for using eye gaze to control robots. There is still significant potential for research in this area. In the field of human health and social work activities, no articles have reported bio-signal sensors, such as EEG and EOG. Most sensors are commercial eye trackers, included in 31 articles, while other sensors, such as RGB cameras, webcams, EOG, and EEG, have been minimally studied. Only five studies use a combination of sensor types. Therefore, there is still much work to be done in this area.

Future research in using eye gaze for controlling robots should explore eye-gaze data acquisition tools outside of commercial eye trackers. The development of an eye-gaze detection algorithm with image processing is indispensable, so that it can be widely used with cheaper and simpler device. Moreover, applications for using eye gaze for robot control also require study.

This review paper's limitation was using Scopus as the sole database source without considering other databases, such as Web of Science. There were some other limitations, such as using document types such as “conference papers and articles,” source document types such as "conference proceedings and journals," and subject areas such as "computer science and engineering."

This article contributes to new knowledge by providing a comprehensive review and analysis of the research trends and advancements in controlling robots using gaze estimation. In this review, we synthesized existing literature using a systematic bibliometric approach, identified vital research themes for controlling robots using eye gaze, and highlighted emerging trends in this area. Thus, it offers insights into the current state of dominant research in the human health area using commercial eye trackers.

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