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Deep Learning-Enhanced SLAM: A Comprehensive Bibliometric Analysis and Research Trends (2019-2024)



Abstract: - Simultaneous Localization and Mapping (SLAM) have become the bedrock of robot autonomy, making mobile robots navigate and understand their environment without any knowledge of it. Since 2019, major interest in the combination of deep learning techniques with SLAM systems has brought breakthroughs in accuracy, robustness, and computing economy. This survey deeply analyses the deep learning-enhanced SLAM frameworks and the contributions of such frameworks on important components such as perception, feature extraction, data association, and loop closure detection. A taxonomy to describe these contributions is also proposed to explain the integration of traditional SLAM approaches and data-driven methods. The analysis provides characteristics of deep learning systems like better feature representation, adaptability to complex contexts, and robustness against sensor noise. However, it also detects issues, such as high processing needs, generalization across varied contexts, and a restricted ability to interpret the conclusions of the neural network. Different datasets and evaluation metrics used to benchmark these algorithms are also examined in great detail in order to understand performance under varied settings. This study continues by outlining new developments, such as multimodal sensor fusion, real-time processing advances, and edge computing advancements, which have the potential to solve present restrictions. The survey not only provides a complete review of current achievements but also identifies avenues for future research, hoping to inspire improvements in deep learning-driven SLAM systems

Keywords: Bibliometric Analysis, Simultaneous localization and mapping (SLAM), Deep learning, Mobile robots, Biblioshiny, VOSviewer.

I. INTRODUCTION

Initially, the manufacturing sectors were the primary domains employing autonomous mobile robots. Recently, it has been increasingly utilized in various areas, including medicine, military, mining, and agriculture. The robot in motion must be given cognitive data to model its surroundings, localize its precise location, and recognize and avoid obstacles utilizing a particular path-planning technique. Selecting the suitable path-planning technique is essential for enabling the robot to traverse a congested area from a specified starting point to the destination while avoiding obstacles. There are two types of robot navigation: local navigation and global navigation. In the context of global navigation, for instance, the arrangement of parts is determined with regard to an orientation axis while traveling toward the destination. Subsequently, the dynamic limits of the environment are determined, and the linkages amongst each arrangement of elements are formed.

A. Mobile robot path-planning and motion

The fields of artificial intelligence, computer vision, and robotics have all contributed to important breakthroughs in the field of mobile robot motion and path planning. These developments led to considerable progress. [1] Studied the detection of dynamic human-object interaction in scenarios that included mobile robots. They underscored the importance of real-time visual SLAM to enhance the adaptability of robots in dynamic environments. Their study underscores the need for strategies that can robustly extract features to enhance the navigation of robots in challenging environments.

Moreover, [2] showed how to control mobile robots in flat areas with actor-critic algorithms and artificial intelligence. The proposed methods were tendered similarly. The results of their research foregrounded the trend of utilizing reinforcement learning architectures for adaptive path planning in structured terrains. This technique not only raised efficiency but also showed the tractability of ML techniques in the field of robotics applications.

Another seminal study [3] offered a view shift for sweetening road condition assessment. This advanced kind of road condition assessment permitted us to securely navigate autonomous mobile robots without encountering

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recurrent issues such as weather-inhibited eyes and low light in outdoor robot cognitive processes and used deep learning combined with computer vision.

Building upon the framework of traversal settings with noisy multi-step observations, [4] extended further the capabilities of mobile robots by contributing to the evolution of this framework. Advanced Q-network techniques and deep reinforcement learning were applied in their research to reveal insights into real-time decision-making under uncertainty, a necessary factor for autonomous robots operating in unforeseen situations.

The interdisciplinary nature of this dynamic research field is also manifest in the fact that these studies together underlie a range of methods and technologies that are being deployed in mobile robot motion and path planning.

B. Deep Learning for SLAM in Mobile Robots

Simultaneous Localization and Mapping (SLAM) has emerged as a significant subject in robotics, facilitating autonomous navigation in dynamic settings and enabling mobile robots to traverse effectively. The research has concentrated on addressing the challenges posed by the necessity for real-time performance, dynamic settings, and computational limitations.

For instance, [1] showed that dynamic landscapes mainly reduce the precision of SLAM only to moving objects. A new method, which combines human-object interaction detection into ORBSLAM3, eliminates these effects while maintaining the repaired performance on dynamic datasets like TUM RGB-D. This creation highlights the new emphasis on adaptability in SLAM systems for real-world usage. Similarly, efforts in terms of deploying mobile robots on flat ground have involved actor-critic algorithms as a way to make artificial intelligence work for better optimization of navigation and mapping skills.

Some other major issues of researches in SLAM are path planning and navigation as pointed by [4]. Deep reinforcement learning application shown on navigation systems such as PER-n2D3QN solves the problem of dynamic surroundings by using efficient mechanisms of learning and robust functions of reward. Such novelties have considerably enhanced navigation efficiency and resilience particularly in computationally restricted situations.

Apart from navigation Y. Hu et al. (2024) highlighted another important specific applications such as nuclear facility inspection and outdoor mapping have motivated advances in SLAM techniques. Featureless single-core implementations and LiDAR-inertial SLAM with ground constraints are feasible solutions for resource-limited platforms, ensuring real-time operation and improved accuracy in demanding settings.

Finally, the approach [5] suggested deep learning integration into the process of SLAM, in one case: the P3Net framework, which tends to favor lightweight architectures and gain greater computational efficiency. Those directions represent huge breakthroughs concerning real-time 2D/3D path planning with optimized trade-offs for performance vs. resource consumption. This series of research clearly emphasizes the growing environment of SLAM methods, which meet particular needs in autonomous navigation and mapping across various applications. The development of continuously new algorithms and systems underscores the tremendous impact of SLAM on mobile robotics and promises groundbreaking breakthroughs.

C. Bibliometric Analysis

Bibliometric assessments, as defined by Pritchard [6], are applied statistical and mathematical techniques towards documents and other means of interactions. Bibliometric examination is a prominent form of systematic investigation and decipherment of tremendous amounts of scientific data. It allows us to gain insight into the intricate developmental details of a specific area, and it reveals the emerging subjects in that field [7]. Bibliometric evaluation has been used for systematic review of the development of an opened academic area [8]. It has been used for the analysis of distribution patterns of researchers, topics, journals, key phrases, institutions, and progression themes, and even to predict future research direction from the results of search engines. A Bibliometric evaluation has emerged as a crucial tool for evaluating progress in various scientific domains [9].

The reason for this article is that it attempts to deliberately review and examine the evolution of SLAM utilizing

Deep Learning by examining existing literature, including chronological publication distributions, prominent scientific journals, and frequently used keyword phrases. Utilizing "SLAM" as the primary keyword, we identified over 3,049 articles, which were further classified into 949 principal-linked articles. All of these are mostly sourced from the Scopus Core Collection. We investigated the selected 949 articles by establishing connections among the title, abstract, publication, research study field, citation, the utilized keywords, and geographical distribution. The present study tackles the research disparity in SLAM by applying co-citation of bibliometric, thematic inspection, and cartographic of the literature analysis through a deep-learning evaluation. The primary objective of this review article is to carry out a bibliographic examination attempting to resolve the following questions:

Why has the overall number of publications on SLAM using deep learning grown over time?

Which are the most prominent journals or publication sources for SLAM and deep learning research?

What are the most frequently used keywords in SLAM and deep learning literature, and how have these evolved over time?

Who are the most influential authors, and what are their key contributions to SLAM using deep learning?

Which countries and institutions contribute most significantly to SLAM research with deep learning?

What are the emerging trends in SLAM research influenced by advancements in deep learning?

What types of methodologies and datasets are most commonly used in SLAM research employing deep learning?

What does the bibliometric and cartographic visualization of the literature reveal about knowledge clusters and research networks in SLAM?

II.

METHODOLOGY AND THE DATASETS PROCESS

In bibliometric investigation, we seek to demonstrate associations across articles and also topics of investigation by analyzing the extent to which a work is cited as well as co-cited by other papers. The article is the typical section of the assessment [10], [11]. A key assumption in bibliometric analysis of co-citations is that released works in scientific journals cultivate the research they investigate into articles previously published. meta-analyses of Bibliometric co-citation can assist in expressing underneath shared characteristics across inquiry studies [12].

A. Preliminary Data Collection

A bibliometric search was performed using the Scopus database to thoroughly assess the evolution of SLAM (Simultaneous Localization and Mapping) through deep learning. The search technique was established to locate pertinent articles published from 2019 to 2024. The inquiry focused on articles including the keywords "**Mobile robots**," "**SLAM**," and "**Deep learning**" in the abstract, title, or keywords, thereby emphasizing the convergence of these domains. The search was confined to the **Computer Science (COMP)** discipline to ensure disciplinary relevance. Moreover, only publications designated as research articles ("**ar**") or reviews ("**re**") were incorporated to guarantee the inclusion of primary research and thorough literature evaluations. This method enabled the acquisition of a targeted dataset for subsequent bibliometric and content studies, ensuring that the study thoroughly encompasses recent developments and trends within the specified scope. The process is shown in Fig. 1 below. The code below was extracted from the search results from Scopus, and it shows the algorithm of search in the database after applying filters for refining the last search for the publications to be extracted for the CSV file for bibliometric analysis to be uploaded to RStudio Biblioshiny tool and VOSviewer program to get the graphical interpretation of the data as results.

Scopus 20 | Empowering discovery since 2004

Analyze search results

< Back to results

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TITLE-ABS-KEY(("Mobile robots") AND ("SLAM") OR ("Deep learning")) AND PUBYEAR > 2018 AND PUBYEAR < 2025 AND (LIMIT-TO(SUBJAREA, "COMP")) AND (LIMIT-TO(DOCTYPE, "ar") OR LIMIT-TO(DOCTYPE, "re"))

949 document results

Select year range to analyze: 2019 to 2024 Analyze!

Fig. 1: Scopus Search Results. Source: <http://www.scopus.com>

The Scopus database, managed by Elsevier, is a comprehensive bibliographic resource that encompasses a wide range of disciplines and provides detailed metadata, including bibliographic references, author affiliations, and institutional details [13] [14]. Scopus includes over 25,000 active journal titles spanning multiple domains such as medicine, technology, social sciences, science, humanities, and arts [15]. The database always allows for effective searching with numerous filtering options, enabling users to refine results by criteria such as publication year, subject area, document type, and access type. Scopus also supports advanced features like sorting articles by relevance, citation count, publication date, and usage metrics, providing robust tools for bibliometric and systematic analyses [16].

Scopus was selected for this study due to its broad coverage of high-impact journals and its popularity for bibliometric research, ensuring access to a reliable and diverse dataset. Unlike some databases, such as IEEE Xplore and SpringerLink, which primarily index their own publications, Scopus aggregates a wider range of high-quality sources. While alternatives like Google Scholar were excluded due to concerns about inconsistent data quality and lack of structured metadata, Scopus offers a dependable framework for extracting bibliometric data and analyzing research trends [17] [18].

The topic search was "SLAM using deep learning". The search time frame has been chosen coming from the beginning of 2019 up to the season of 2024 as well. The acquisition time was 2024.11.22. The subject in search provides seeking using keywords, abstracts, and titles of the publications. An aggregate of more than 3049 items before being split into 949 fundamental articles of significance were collected for bibliometric analysis. In this research, the paper's publishing inclinations were first depicted. The assessment concluded based on output and academic focus. The visual observations were additionally offered by employing the program called VOSviewer and Biblioshiny program (From RStudio) [19] owing to its accessibility and great capabilities in bibliometric analysis. R-Studio is an effective instrument for performing bibliometric analysis, and this guide provides detailed instructions for importing and analyzing bibliographic data, displaying citation networks, and computing metrics such as citation counts and h-index. The handbook aims to be accessible to researchers of varying experience levels and is meant to assist those in tourism research in comprehending the scholarly significance of their work and that of their colleagues [20]. The Biblioshiny analysis tool produces an evaluation of research outputs to ascertain annual scientific production, identify the most prolific authors, analyze commonly utilized terms, discover the most prominent journals, and examine collaborative efforts among countries, among other aspects pertinent to the chosen research topic [21].

From the extracted data of the search results, the CSV file has been exported with results of 949 publications to be analyzed with primary analysis from the Scopus database website gave the primary results as follows:

The growth of publications over the period of selected time spans yearly has been displayed in Fig. 2 via the main evaluation of the database maintained by Scopus to show the research focusing on the topic as a hot area of research and the potential and possibility of doing more research to develop more in this area. The figure depicts the annual growth trend in the number of documents indexed in Scopus from 2019 to 2024. The data shows a steady increase over the years, reflecting a growing research output. Starting at a modest level in 2019, the number of publications rose consistently, with a notable acceleration from 2021 onward, reaching its peak in 2024. This trend highlights the expanding focus and interest in the field under study, potentially driven by

advancements in the subject area and increased funding or collaboration opportunities. Such expansion highlights the ever-changing and transforming characteristics of the research sector.

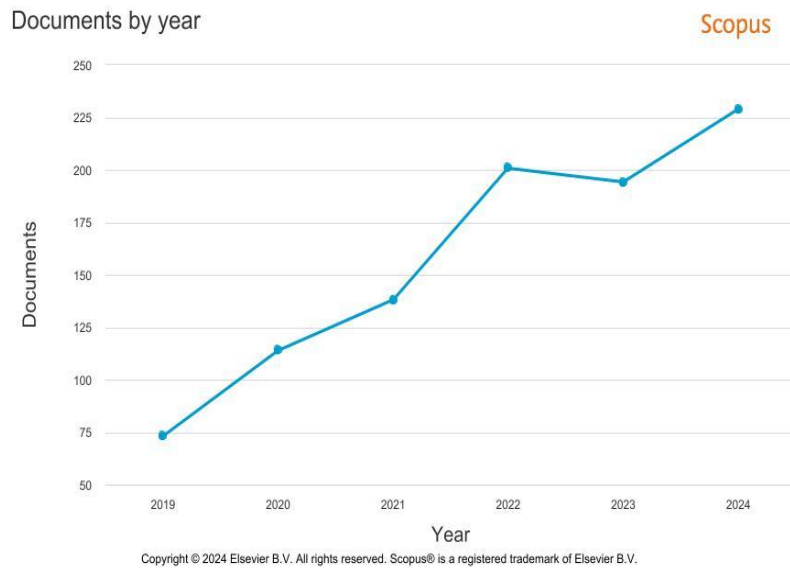


Fig. 2: Publications count till 22.11.2024

The documents by subject area have also been investigated with the primary analysis of the Scopus database and interpreted in the graphical graph as shown in Fig. 3. The figure illustrates the distribution of documents by subject area, as indexed in Scopus. Computer Science dominates with **37.3%** of the total publications, reflecting its central role in the research field. **Engineering** follows as the second most significant area, contributing **29.2%** of the publications, indicating its strong interdisciplinary connections with computer science. Other notable fields include **Mathematics (10.5%)**, **Physics and Astronomy (5.9%)**, and **Materials Science (5.4%)**, which highlight the technical and analytical underpinnings of the research domain. Smaller contributions from **Biochemistry, Genetics (4.0%)**, **Chemistry (3.9%)**, and **Chemical Engineering (1.4%)** show the broader applicability of the research across various scientific domains. Fields like Medicine and Neuroscience, along with the "Other" category, account for marginal shares, collectively indicating less focus in these areas. Overall, the distribution underscores the prominence of computational and engineering disciplines in the research corpus, and it shows that computer science is the most focused area as per search results:

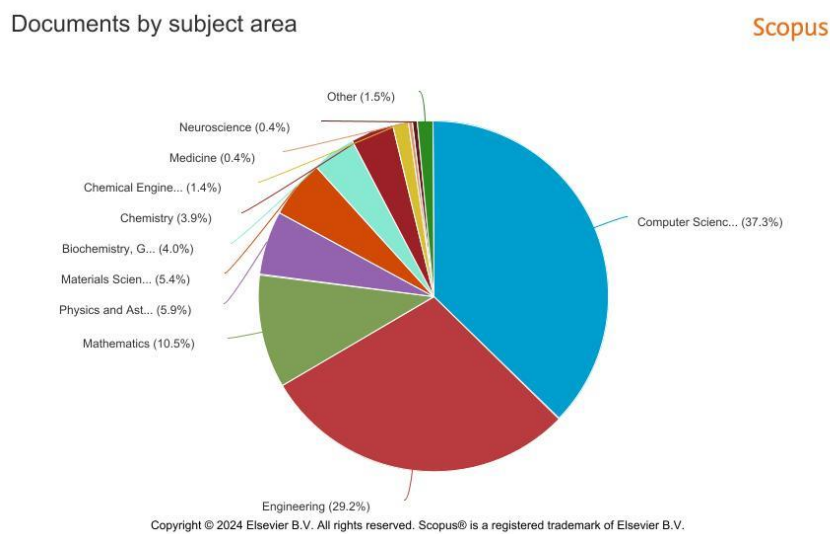


Fig. 3: The subject area of Publications.

The documents per year by source have also been investigated with the primary analysis of the Scopus database

and interpreted in the graphical graph as shown in Fig. 4. The chart illustrates the annual publication trends across five notable sources in robotics and automation research from 2019 to 2024. Notably, Sensors consistently produced a high volume of documents, peaking around 2021 before declining slightly. In contrast, IEEE Robotics and Automation Letters have shown steady growth, overtaking other sources by 2024. IEEE Access demonstrated a sharp increase initially but declined after 2020, while Applied Sciences Switzerland showed gradual and consistent growth. Meanwhile, the Journal of Intelligent and Robotic Systems Theory and Applications maintained a relatively steady output over the years, emphasizing its stable contribution to the field. These trends highlight varying publication dynamics and influence across journals in this domain, and it shows the most sources and journals focused on publications as per search results:

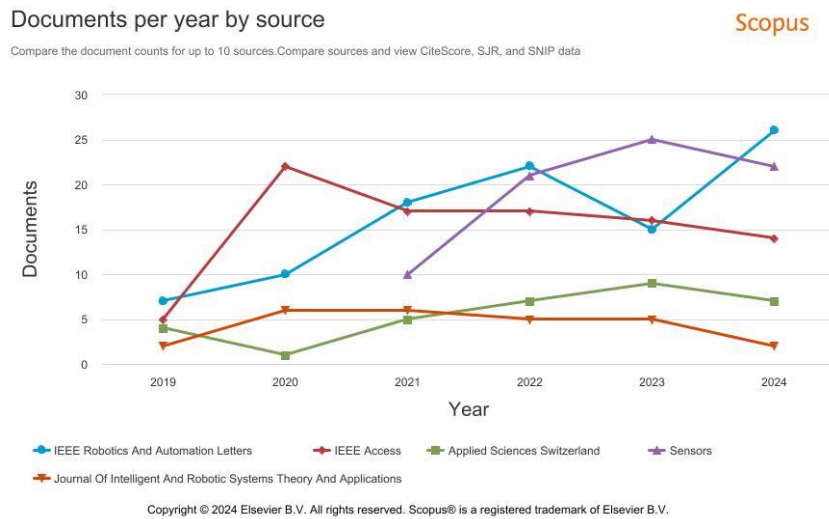


Fig. 4: The Sources and Journals highly focused publications.

The stats and numbers of publications from the sources above have been extracted and counted for the years 2019 to 2024, according to most journal publications. Between 2019 and 2024, the analysis reveals consistent growth in publications across major journals. The **IEEE Robotics and Automation Letters** demonstrated the highest growth, increasing from 7 articles in 2019 to 98 in 2024. Similarly, **IEEE Access** showed a significant rise, publishing 91 articles in 2024 compared to only 5 in 2019. **Sensors** and **Applied Sciences (Switzerland)** exhibited moderate increases, with **Sensors** growing to 78 publications in 2024 and 33 publications in 2024 corresponding. The **Journal of Intelligent and Robotic Systems** also showed notable growth, peaking at 26 publications in 2024. These trends underscore the expanding focus on robotics and automation technologies in scholarly research. These results taken from further analysis of the outcome of the RStudio Biblioshiny tool from the source of Excel file been extracted as the name of source production over time, including the most publishing journals in the field with the numbers of publications yearly for the top journals as mentioned in Table 1 below to show the growth of publications within the discipline of the topic throughout a certain span.

Table 1: Yearly Distribution of Publications Across Key Journals (2019–2024)

Year	IEEE Robotics and Automation Letters	IEEE Access	Sensors	Applied Sciences (Switzerland)	Journal of Intelligent and Robotic Systems
2019	7	5	0	4	2
2020	17	27	0	5	8
2021	35	44	10	10	14
2022	57	61	31	17	19
2023	72	77	56	26	24
2024	98	91	78	33	26

The analysis of publication languages in the dataset reveals a strong dominance of English as the primary medium of scholarly communication. Out of a total of 949 publications, **874 articles (92.1%)** are published in English, underscoring its status as the lingua franca of scientific research. Non-English publications constitute a smaller proportion, with **Chinese** being the second typically observed language acquisition, which includes **51 publications (5.4%)**, followed by **Korean** with **19 publications (2.0%)**. Other languages, including **Spanish, Russian, and Portuguese**, have minimal representation, with **two publications (0.2%)** each for Spanish and Russian and **one publication (0.1%)** for Portuguese, as shown in Table 2. These findings highlight the predominance of English in disseminating research findings while recognizing the contributions of non-English publications in regional contexts. This data was retrieved from Scopus.

Table 2: Distribution of Publications by Language.

Publication Language	Number of Publications
English	874
Chinese	51
Korean	19
Spanish	2
Russian	2
Portuguese	1

Source: <http://www.scopus.com>

An analysis of the top author keywords in the dataset highlights the core thematic areas of research. The keyword "Mobile Robots" is the most frequently occurring term, appearing in 543 publications, reflecting robotics' centrality in this body of work. "Deep Learning" follows closely with 449 occurrences, underscoring the significant integration of advanced machine learning approaches in the discipline. The foundational concept of (SLAM) "Simultaneous Localization and Mapping" is featured in 215 publications, demonstrating its importance in enabling autonomous operations for mobile robots. Keywords such as "Mapping" and "Navigation," appearing in 180 and 178 publications, respectively, further highlight the critical focus on spatial awareness and pathfinding technologies. Collectively, these top keywords reveal a strong emphasis on integrating robotics and deep learning to advance autonomous navigation and spatial intelligence systems. All data are taken from Scopus as stated and mentioned in Table 3 below.

Table 3: Top Five Author Keywords and Their Occurrences in Publications.

Author Keywords	Occurrence (Number of Publications)
Mobile Robots	543
Deep Learning	449
Simultaneous Localization and Mapping	215
Mapping	180
Navigation	178

Source: <http://www.scopus.com>

The information emphasizes an overall decrease in the number of papers for six years from 2019 to 2024. The peak of research activity occurred in **2019**, with **229 publications**, marking the most productive year in this timeframe. However, a steady decrease is observed thereafter, with **194 publications in 2020** and **201 in 2021**, followed by a sharper decline in subsequent years, reaching **138 publications in 2022** and **114 in 2023**. The preliminary count for **2024** stands at **73 publications**, suggesting a continuation of this downward trend. This

reduction in publication volume could indicate a shift in research focus, reduced funding, or saturation in the field. Further analysis may be needed to identify the underlying factors contributing to this pattern. Table (4) shows the stats of the annual distribution of publications over the time span.

Table 4: Annual Distribution of Publications (2019–2024).

Year	Number of Publications
2019	229
2020	194
2021	201
2022	138
2023	114
2024	73

Source: <http://www.scopus.com>

D. Overview of Literature Forms and Geographic Contribution Analysis

The bibliometric review that was carried out sheds light on the forms of literature that are accessible. In the next section, we will discuss the differences between the many pieces of literature that are now available, as well as the geographic spread of the authors' contribution, those places in which the papers were published, and the various affiliation statistics.

III. RESULTS AND DISCUSSIONS

A. The Publication Topic Trends

This bibliometric investigation demonstrates a dynamic landscape of research trends in robotics throughout the period 2019 to 2024. The phrase "robotics" constantly ranks high, showing its central position in the area. The incorporation of artificial intelligence, especially deep learning and reinforcement learning, has garnered considerable momentum, propelling progress in robotic autonomy and learning capacities. Mobile robotics and SLAM have also emerged as significant areas of focus, enabling robots to navigate and interact with complicated environments. The increased interest in agricultural robots underlines the potential of robotics in tackling global food security concerns. These tendencies indicate a favorable future for robotics, emphasizing the creation of intelligent, adaptable, and socially advantageous systems. The publication trends are shown in Fig. 5 as an interpretation for the analysis of RStudio Biblioshiny.

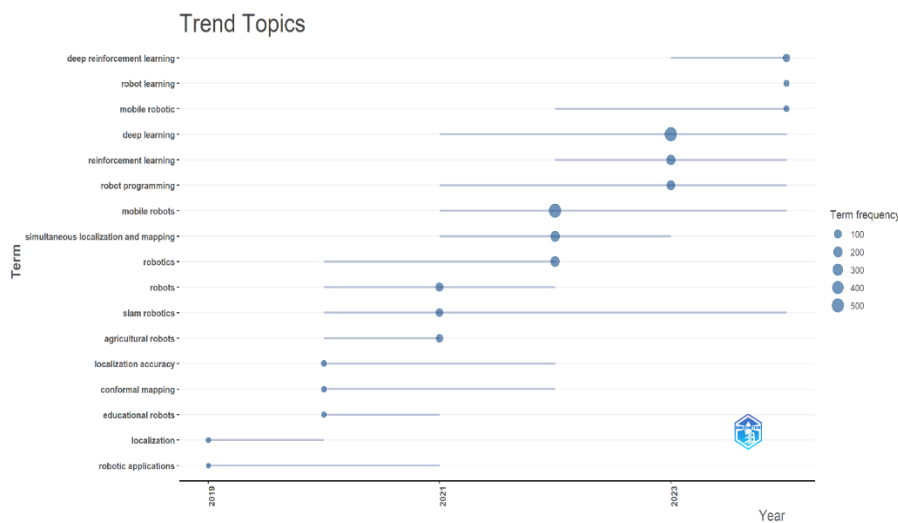


Fig. 5: Evolution of Robotics Research Trends (2019-2024).

B. Analysis based on Countries and Regions

The map displays the global distribution of scientific production, with China rising as a prominent power. This trend is particularly pertinent to the field of mobile robotics employing deep learning. China's large research output in this area is obvious, possibly contributing to breakthroughs in autonomous navigation, object identification, and human-robot interaction. As a prominent player in both hardware and software development, China's effect on the future of mobile robotics is important. This visualization emphasizes the global collaboration and competition necessary to foster innovation in this fast-expanding industry. The map in Fig. 6 illustrates the most dominant country in the field of research in the topic specified and extracted out of the Scopus record and examined and evaluated using Biblioshiny from RStudio software.

Country Scientific Production

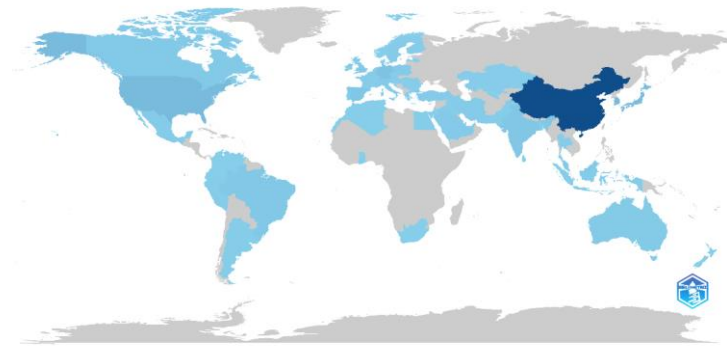


Fig. 6: Global Scientific Production.

The bar chart shows a comparative examination of scientific document output across ten countries/territories. Notably, China leads the way with a substantially bigger number of documents, underlining its enormous contribution to worldwide research. South Korea, the United States, and Japan follow closely, exhibiting their enormous research output. While Germany, India, Taiwan, the United Kingdom, Spain, and Australia demonstrate a lower volume of scientific publications compared to the top three countries, they nonetheless contribute significantly to specialized study areas. This animation displays The worldwide distribution of scientific research endeavors and points out the vital importance of international collaboration to improve knowledge and address global concerns. Fig. 7 shows the bar chart of countries and territories with the most contributions in the field of research. Also based on the analysis of the CSV file and investigation done by Biblioshiny there the result of the analysis of the most cited country shows Korea as the most cited with a total citations of 654 and average article citations of 8.80 as the mentioned information depicted in Fig. 8 below. In Fig. 9 The line graph depicts how scientific productivity increases with time for five countries: China, Germany, Japan, Korea, and the USA. China is the country with the biggest increase in scientific production, having a steep climb from 2019 to 2023. Germany, Japan, Korea, and the USA also demonstrated a growing tendency of scientific publications over this time although at a considerably slower pace than China. This animation displays China as an expeditious growth planetary scientific powerhouse and stresses worldwide cooperation in addressing global challenges with the purpose of innovation generation.

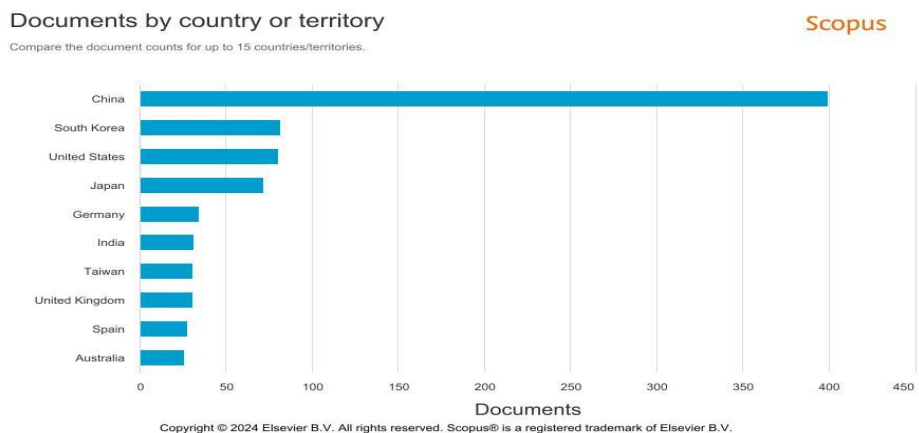


Fig. 7: Country-wise Document Output.

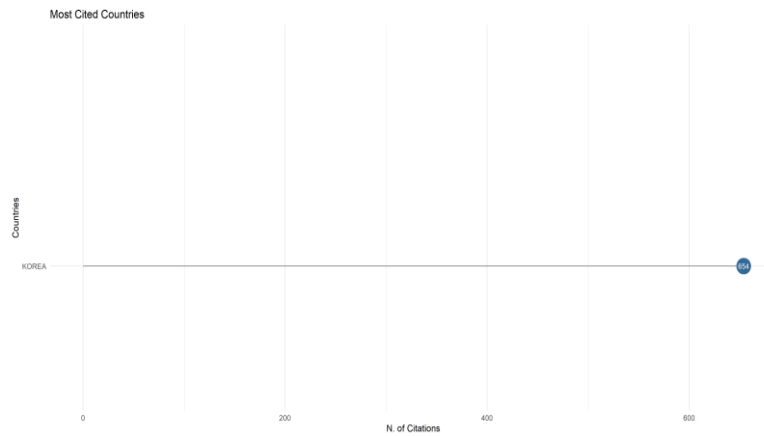


Fig. 8: The Most Cited Countries.

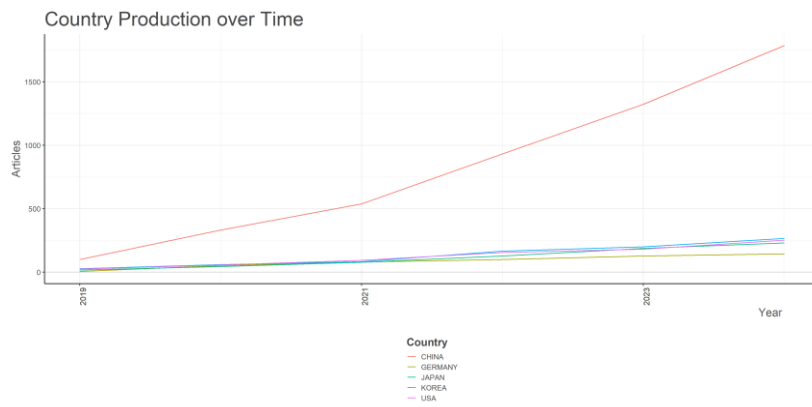


Fig. 9: A Rising Tide: Global Scientific Production Growth.

Table 5 in Table shows that China is at the top of the output of research from 2019 to 2024. China has always had the highest number of annual papers produced, with a large increase in the number year after year. Germany, Japan, Korea, and USA follow, showing a year-on-year increase in their scientific production. Yet the expansion of China is accelerating more than the others while cementing its position among the world's leaders. This trend underlines international cooperation in generating innovation as well as addressing global issues.

Table 5: Top 5 Countries by Research Output (2019-2024).

Year of Publications \ Country	2019	2020	2021	2022	2023	2024
China	101	333	539	932	1322	1785
Germany	7	53	81	101	129	145
Japan	18	45	79	129	188	232
Korea	28	60	83	167	201	267
USA	26	57	94	156	182	253

C. Affiliations based Analysis

As illustrated in Fig. 10 here, the bar chart enables an exploratory examination of articles published in research journals among the top 10 linked China institutions. The Ministry of Education (MoE) of the People's Republic of China leads the race by creating the most number of documents, followed by the (CAS) Chinese Academy of

Sciences, a close second. This clarifies an important drive to develop and create the innermost of these universities. The further affiliations, such as ZU, USTC, and BIT, others, also show significant research crop that contributes to the whole scientific productiveness of China. This graphic emphasizes the targeted research efforts inside these elite universities and their collective contributions to the scientific progress of China. The comparison was done and analyzed based on the Scopus database.

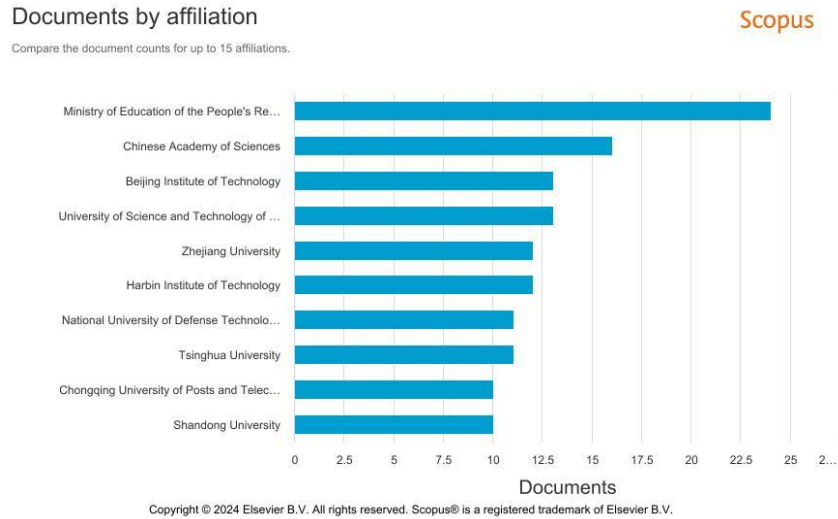


Fig. 10: Analysis Based on Affiliations Contributions.

The line graph represents the publication of research over time by the five most prominent Chinese affiliations: the University of Science and Technology of China, Shandong University, National University of Defense Technology, Zhejiang University, and Wuhan University of Science and Technology. While all affiliations showed a large rise in research production from 2019 to 2023, the Shandong University (SU) and the National University of Defense Technology (NUDT) show exceptionally rapid development. This shows a strong effort in research and development among these institutions. The image emphasizes the competitive landscape of research in China, with various institutes contributing to the country's total scientific growth. In Fig. 11 as shown below all the data taken from Biblioshiny and interpreted in the above explanation as compared to the analysis in Fig. 10 in the previous paragraph.

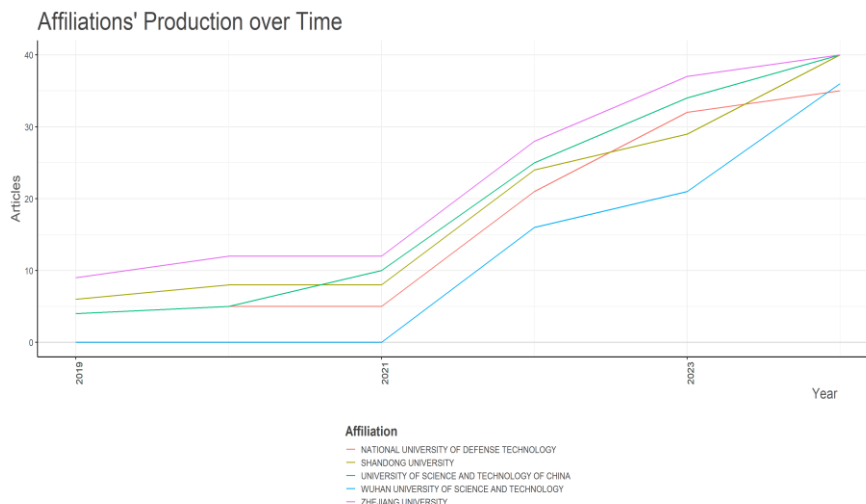


Fig. 11: Affiliations Production over Time.

Table 6 shows the lists of the top ten affiliations across China sorted by the number of research articles published. Zhejiang University (ZU), the University of Science and Technology of China (USTC), and Shandong University (SU) lead the way with 40 articles each, proving their considerable contribution to the

country's research output. The additional affiliations, including the Wuhan University of Science and Technology, the National University of Defense Technology, and others, also demonstrate strong research activity, contributing to China's overall scientific progress. This analysis illustrates the concentrated research efforts inside these top universities and their cumulative impact on China's scientific scene. The data in the table extracted from Biblioshiny as an Excel file and then interpreted in this paragraph supported the data in Table 6.

Table 6: Most Relevant Affiliation Publications.

Affiliation	No of Articles
Shandong University (SU)	40
University of Science and Technology of China (USTC)	40
Zhejiang University (ZU)	40
Wuhan University of Science and Technology (WUST)	36
National University of Defense Technology (NUDT)	35
Chongqing University of Posts and Telecommunications	33
Northeastern University	33
Tsinghua University	29
Huazhong University of Science and Technology	27
Inst. of Robotics and Mechatronics	27

D. Analysis Based on Author Publications

The examination of papers by author publications, as depicted in the Scopus database, underscores the contributions of prominent researchers in the field. Ge, G. was the most prolific author, with eight documents assigned to their name, substantially exceeding the publication volume of other contributors. Seo, K.H., Wang, W., Yang, K.M., and Zhang, Y. each own five published documents, demonstrating significant involvement in the research domain. Authors like Zhou, F., Cebollada, S., Hu, L., Kwak, J., and Miura, J. have each made significant contributions, with four articles apiece. As shown in Fig. 12.

This distribution indicates a varied and dynamic research community, with Ge, G. potentially serving a crucial role in the advancement of the discipline. The aggregation of writers with four to five publications signifies a collaborative and competitive research landscape. These results underscore the significance of prominent academics in guiding the trajectory of the research domain, while also pinpointing prospective centers of competence and collaborative prospects.

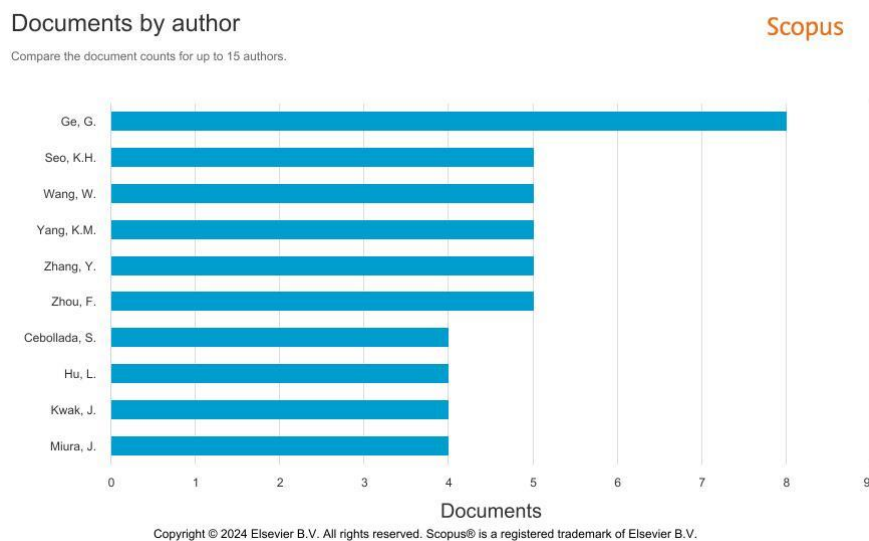


Fig. 12: Top Contributing Authors in SLAM Research Utilizing Deep Learning (2019–2024): Document Counts from Scopus Database.

The bibliometric analysis reveals that Ge, G. is the most prolific author, contributing eight documents to the field, while other prominent authors, such as Seo, K.H., Wang, W., Yang, K.M., and Zhang, Y., have each contributed five documents. This distribution highlights Ge, G.'s significant role in advancing research on SLAM (Simultaneous Localization and Mapping) with deep learning integration. The uniform contribution among other key authors suggests a collaborative and distributed research effort, indicating growing interest and engagement in this domain. Such data can be instrumental in identifying leading researchers and potential collaborators in the field. Table 7 shows only the top five contributed authors and their counts of documents and publications in the field in the specific period. The data is extracted and analyzed from the Scopus database.

Table 7: Top Authors and Their Document Contributions in SLAM Research Utilizing Deep Learning (2019–2024).

Author	Document Count
Ge, G.	8
Seo, K.H.	5
Wang, W.	5
Yang, K.M.	5
Zhang, Y.	5

Source: <http://www.scopus.com>

Fig. 13 shows the examination of authors' output over time, conducted with Biblioshiny in RStudio, which offers insights into publication trends and the influence of prominent contributors in the domain of SLAM research employing deep learning. The timeline (2019–2024) demonstrates that writers such as Wang, Wei, and Ge, Gengyu exhibit steady research output with many articles dispersed across the observed period, showing their persistent contributions to advancing the subject. Notably, Wang, Wei demonstrates a peak in 2021 with the largest amount of documents and citation exertion ("Total Citations per Year (TCpY)"), indicating strong influence during this year.

Other authors, notably Seo, Kap-Ho, Yang, Kyon-Mo, and Zhang, Yi, continue constant contributions with fewer but powerful papers. The bubble sizes in the graphic denote "Number of Articles" (N.Articles), while the shading intensity reflects the "Total Citations per Year" (TC per Year). This gives a dual perspective on production and influence. For instance, whereas Ge, Gengyu maintains a consistent production, the associated citation patterns show increased recognition over time. This temporal analysis not only highlights prolific contributors but also sheds light on the dynamic nature of research activity on the subject, aiding in discovering emerging leaders and important work. Such data gives significant assistance for spotting patterns and potential cooperation in the field.

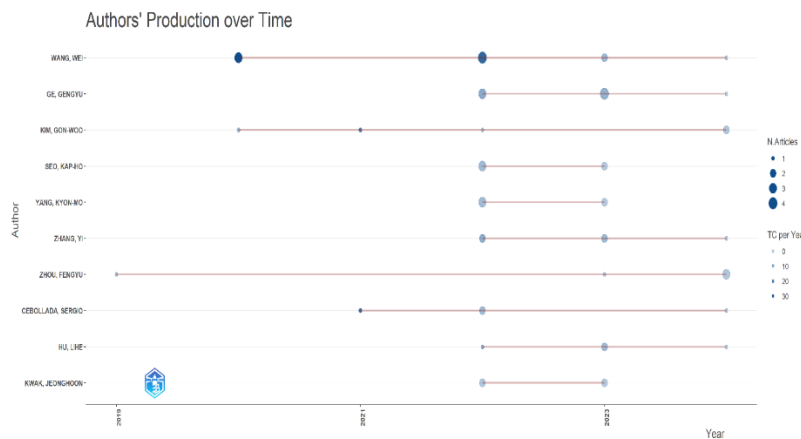


Fig. 13: Authors' Research Output and Citation Impact Over Time (2019–2024) Based on Biblioshiny Analysis.

Table 8 shows significant bibliometric indicators such as the starting year of publication (PY_start), number of publications (NP), total citations (TC), m-index, g-index, and h-index for ten prominent authors in SLAM research leveraging deep learning. These indicators provide a comprehensive assessment of the writers' productivity, citation impact, and consistency in research output.

Among the authors, Wang Wei stands out with the highest h-index (6) and g-index (10), demonstrating strong academic influence and a wide reach of their writings. Their highest number of published documents (10) and the total citations (266) further prove their significance in the field since they started their research activities in 2020.

Also, important contributions are given by Miura Jun, Cebollada Sergio, and Ge Gengyu. The latter in fact keeps his h-index equal to 4, totaling 72 citations, the former instead offers a considerable citation number equal to 110 with balanced h- (3) and g-index (4). On the other side, Ge Gengyu exhibits excellent productivity as he published 8 publications along with a potential m-index at 1.0 thus suggesting an early stage yet considerable contribution since the year 2022.

Algabri Redhwan, Behley Jens, and more have similar bibliometric indices showing increasing influence over the topic. M-index is another measure that transforms the h-index by the overall number of years through the first publication; it, therefore, underscores the consistent output of the authors with time. For instance, Behley Jens and Cebollada Sergio both have significantly higher m-indices at 0.75, signifying their continuous input since their starting point in 2021.

This analysis underlines the range in the authors' effect, showing both well-established contributors and new researchers in SLAM and deep learning integration. Such indicators are very useful for understanding the research landscape that is developing. This way, standards are established for academic influence and productivity.

Table 8: Impact Metrics of Top Authors in SLAM Research Utilizing Deep Learning (2019–2024)

Author	h_index	g_index	m_index	TC	NP	PY_start
Wang Wei	6	10	1.2	266	10	2020
Miura Jun	4	4	0.8	72	4	2020
Algabri Redhwan	3	3	0.6	83	3	2020
Behley Jens	3	3	0.75	56	3	2021
Cebollada Sergio	3	4	0.75	110	4	2021
Choi Mun-Taek	3	3	0.6	83	3	2020
Gambardella Luca maria	3	3	0.5	43	3	2019
Ge Gengyu	3	6	1	42	8	2022
Giusti Alessandro	3	3	0.5	43	3	2019
Guzzi Jerome	3	3	0.5	43	3	2019

E. Bibliometric Network Analysis

E. 1. Network analysis of VOSviewer

Co-authorship analysis for author keywords visualization is shown in Fig. 14 for the network map of keywords from VOSviewer for the bibliometric analysis, which will be interpreted and well-explained in this subsection of results and discussion showing different clusters and how they are connected. VOSviewer's network map of author keywords provides an instructive insight into the direction of trends and interrelationships of this SLAM

mapping	175
reinforcement learning	165
navigation	156
robot programming	143
motion planning	122
indoor positioning systems	114

Fig. 18 shows that according to Treemap, the majority of terms are "deep learning" and "mobile robots" with 11%, "reinforcement learning" and "mapping" with 9%, and 4.9 % in order. The following major terms follow "simultaneous localization and mapping," "robotics at 4% each" and "robot programming, which also reached 3 %". It points out how deep is the increasing importance of the research of AI-led technology in robotics, independent navigation, and perception, as well as in the area of learning.

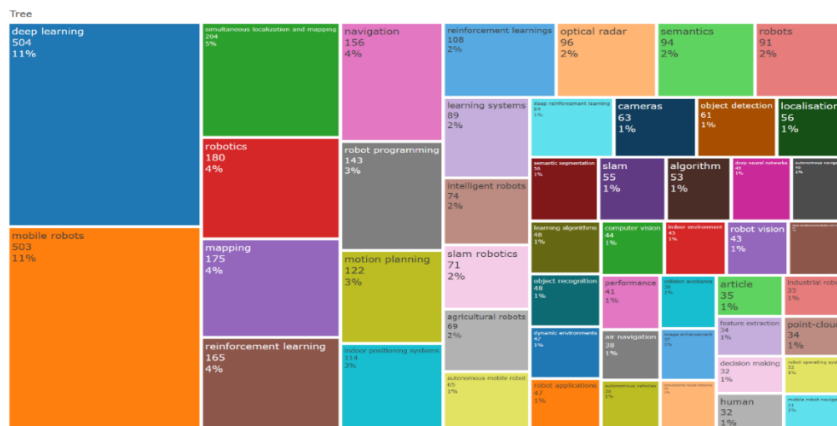


Fig. 18: Term Frequency Treemap: Key Concepts in Robotics Research.

The collaboration network shown here really helps in insights into the interrelation of the people working in the domain of Mobile robots as exemplified in Fig. 19. This network comprises noticeable distinct clusters. A cluster is an aggregate of the researchers whose work is closely interrelated. A most prominent one of them is seen with Wang Wei. The researchers are reportedly focused on SLAM. The other cluster, centered around (Seo Kap-ho), seems to be interested in Navigation. Though these clusters are not identical, interconnections exist between them, which hints that cross-disciplinary collaborations are possible as well as shared research interests. In general, the network topology presumes a moderate level of connectedness among these researchers who are hubs in some of the nodes. It exhibits dynamism in this scientific community with knowledge and ideas being shared and transmitted. However, there are also cases of solitary nodes, which can be researchers who may benefit from better communication. By finding critical clusters and links, this network analysis can inspire methods to boost collaboration, discover possible research alliances, and stimulate interdisciplinary study within the subject of Mobile robotics.

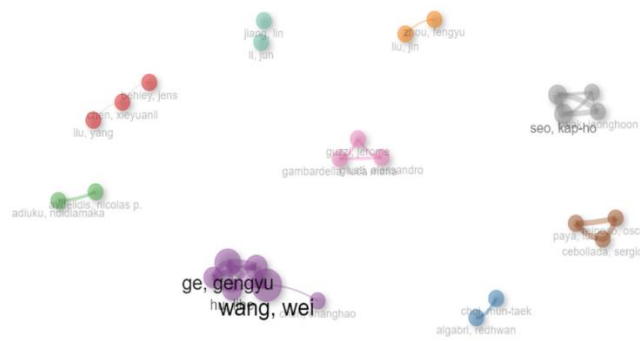


Fig. 19: Collaboration Network of Key Researchers in Mobile Robots.

F. Discussion and Future Scope

This discussion was upon the recent work on SLAM technologies that we survey papers as follows. The latest research in SLAM has shown discoveries with contributions toward complex real-world applications, sparse features, and dynamic environments. Wang Wei et al. (2024) proposed an advanced feature point extraction approach for VSLAM in low-light dynamic conditions. This strategy helped dramatically increase localization accuracy as well as robustness against dynamic, poorly lit scenes by incorporating advanced filtering techniques and enhancement. However, this work reveals a deficiency in computational efficiency, the barrier to large-scale real-time systems [22].

For curved indoor spaces, Wang Wei (2023) presented a visual-feature-based localization mode for mobile robots in long corridors. The method reduces interference from periodic patterns and improves localization precision with multiple visual features. Experimental results had fewer localization errors in structured environments but robustness and scalability under varying illumination conditions need further research [23]. Similarly, Wang Wei (2023) has proposed a semantic structure graph to improve the working of re-localization and loop closure detection in VSLAM systems. The process involves topological links with semantic data, which enhanced the robustness of the system in dynamic environments, and diminishes false positives during the process of loop closure detection, but the computational cost associated with processing semantic data is a hot area for future study work [24].

In healthcare-related applications, Wang Wei, in 2022 proposed a hybrid technique of laser-based SLAM with text feature recognition for the localization of mobile robots within hospital corridors. The technique efficiently solved feature-sparse difficulties by using textual features to boost localization performance. While the strategy has promising potential, its validation in real-world hospital scenarios and bigger datasets is important to establish its generalizability [25]. Apart from that, Wang Wei proposed SO-SLAM as a semantic object-based SLAM system with scale proportionality and symmetrical texture constraints in 2022. This brought about important improvements in the reliability and precision of mapping in situations with scale equivocalness or scarce features. However, the scalability and computational cost of multi-agent SLAM scenarios are still important areas to be explored further [26].

Overall, the work is part of developing SLAM techniques that could be considered for overcoming constraints in challenging dynamic scenarios while continuing to develop real-world boundaries. To realize the promises of such creative systems fully in their various applications and also in less resource-rich environments, further breakthroughs are needed, especially in terms of efficiency and scalability in computing.

The future of SLAM research promises highly transformative breakthroughs, stimulated by the critical needs in dynamic and resource-constrained scenarios. Among the principal thrusts will be the addition of powerful machine learning models, notably lightweight, sophisticated deep learning architectures, to enhance the computational efficiency of semantic SLAM systems. Other important directions are in the development of robust algorithms that should attain high accuracy with a speed of real-time under low-light or feature-poor

conditions. Further development will be important in making multi-agent and collaborative SLAM scalable in facilitating smooth data exchange and synchronization between robots. Finally, scalability is a requirement that makes robustness improvements in healthcare applications, or critical applications operating in varying unpredictable environments. The integration of many sensor modalities, such as LiDAR, cameras, and inertial sensors, as well as context-aware semantic data processing, will probably characterize the next generation of SLAM systems. Other substitutes for aggravating computational bottlenecks in the system, such as through hardware acceleration, such as edge computing or FPGA-based implementations, are also obtainable for resource-constrained platforms. These developments, combined with an increasing focus on resilience and adaptability, will revolutionize mapping and self-navigating, making SLAM more persuasive in application across industries such as health care, autonomous vehicles, and logistics.

IV.

LIMITATIONS OF THE STUDY

This analysis is narrow in scope since it focuses only on the publications between 2019 and 2024 from the Scopus database, thereby excluding relevant contributions from other high-impact databases such as IEEE Xplore, Springer, or ACM Digital Library. Although the research provides a comprehensive bibliometric analysis of deep learning-driven SLAM, it may not have delved into emerging subdomains, such as lightweight neural network designs for real-time SLAM, the role of explainable artificial intelligence (XAI) in improving the interpretability of SLAM systems, and advancements in SLAM for swarm robotics. Not as well explored are interdisciplinary applications of SLAM: for example, in the domains of augmented reality, precision agriculture, and underwater robotics. This leaves a void on how SLAM might scale to different contexts. Another limitation is that the study does not include unpublished papers, patents, and technical reports. Hereafter research could fill in the gaps by studying broader datasets, providing deeper insights, and combining interdisciplinary viewpoints into less-covered but captivating areas, such as SLAM in resource-constrained situations or sustainability-driven SLAM frameworks. This piece of work is a groundwork for others to build on, and inspire more holistic research studies in this space-growing subject.

V. CONCLUSIONS

This is a comprehensive review of the applications of deep learning to SLAM, including recent insights into the challenges still underway. Due to the incorporation of deep learning, SLAM systems obtained tremendous improvement in dealing with complex environments, robust feature extraction, and sensor noise. Nonetheless, these approaches present certain intrinsic difficulties, such as elevated computational expenses, confined applicability across obscure characteristics, and the different contexts of neural networks, which adversely influence interpretability.

This work discusses the particular contributions of deep learning to special SLAM components like loop closure detection, data association, and perception. To classify these advances in a structured manner, taxonomy is introduced. Although it has its shortcomings, some potential lines of research are sensor fusion, real-time performance optimization, or edge computing, which may perhaps herald a future when deep-learning-driven SLAM becomes practically viable in dynamic and resource-constrained scenarios. Addressing the above limitations, researchers may develop SLAM systems to the next degree of autonomy and intelligence through generalization, reduction in compute cost, and improvement in interpretability. This survey should be the basis of future work motivating more research and innovation in this fast-changing field of mobile robotics and SLAM.

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