Developing Cognitive Abilities in Robots: A Bibliometric Overview of AI and ML Applications

Khaled Obaideen, Mohammad AlShabi, and Stephen Andrew Gadsden

Abstract The domain of cognitive robotics has gone through many technological innovations, majorly enhanced by the adoption of Artificial Intelligence (AI) and Machine Learning (ML) concepts. This study performs comprehensive bibliometric analysis, using tools like VOSviewer and Biblioshiny, to map the development, the existing scene and the future prospects of cognitive robotics studies since 1953. We address how AI and ML expand robotic abilities, marking the shift from early development phase to the period of fast evolution and improvement. The remarkable results show an increasing trend starting from mid- 1980s with a peak in the late 1990s and an exponential growth in the last ten years which highlights the growing impact and the broadening usage in different fields. The paper shows cross functional aspects of cognitive robotics, which combines biological and cognitive approaches with progress of technology. The two main areas of robots cognitive robotics are human–robot interaction and autonomous decision-making. The ability of robots to acquire knowledge, self-adaptability, and robot operation in human-centered environments is highlighted, as well as the practical problems that may come from robot autonomy and superior cognitive capacities. From this bibliometric study, we get key insights concerning the past and present of cognitive robotics which form the basis of future studies. The study reinforces the necessity of a multi-pronged approach in robotics, with progress aligned with the needs of society, to ensure the responsible deployment of cognitive robots.

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1 Introduction

Rapid advancements in the domains of Artificial Intelligence (AI) and Machine Learning (ML) are currently shaping a new era of technological capabilities and posing unique challenges, particularly evident in the field of robotics [1–5]. This scholarly work is focused on examining the integral role played by AI and ML in addressing the complex cognitive challenges inherent in robotics. The implications of this exploration are vast, impacting society at large, advancing the discipline of robotics, and echoing across the wider scientific and technological community.

The integration of AI and ML to enhance the cognitive capabilities of robots carries significant societal implications [6–8]. As robots become more ingrained in our daily existence, their advanced ability to perceive, comprehend, learn, and autonomously make decisions is poised to revolutionize various industries, redefine healthcare delivery through improved precision and personalization, and transform the dynamics of everyday human–robot interactions. The ramifications of these developments are profound and far- reaching, heralding a transformative era in the way humans interact with and utilize robotic technology.

Within the academic sphere, the application of AI and ML in marks a burgeoning field of research [6, 9–13]. This pursuit is not merely about enhancing robotic functionality; it represents a quantum leap in our endeavour to endow machines with human-like cognitive abilities. This exploration stretches the existing boundaries of technology, challenging conventional paradigms and sparking innovation in areas such as algorithmic development, machine perception, adaptive learning, and autonomous decision-making. It is a journey that invites a re-evaluation of the capabilities of robots, urging us to reimagine the potential of these artificial entities.

Significantly, this study underscores the importance of comprehensively understanding the role of AI and ML in robotics from a cognitive perspective. It scrutinizes the current state of research, evaluates the progress made, and identifies areas that necessitate further studies. In doing so, the paper contributes to the broader discourse on the future of robotics, offering valuable insights and guidance for researchers, policymakers, and practitioners in the field.

2 Methodology

In the study tailored methodology was utilized, as illustrated in Fig. 1. This methodology is a synthesis of advanced bibliometric and data analytic techniques, specifically aimed at extracting a rich blend of quantitative and qualitative insights into the application of AI and ML in addressing cognitive challenges in robotics. Reflecting the best practices in bibliometric research [14–20], this approach ensures a comprehensive, multidimensional examination of the roles AI and ML play in enhancing cognitive functions within the field of robotics.

The primary data source for this research was the Scopus database, chosen for its extensive repository of scholarly articles. Precise search queries were formulated, as detailed in Fig. 1, concentrating on terms such as “AI,” “Machine Learning,” and their various applications in addressing cognitive issues in robotics. These queries were intricately designed to selectively extract publications that accurately reflect the integration of AI and ML in solving cognitive challenges in robotics, thereby ensuring the relevance and precision of the collected data. The timeline for this study spans from the early developments in these technologies to the end of 2023, providing a broad historical and contemporary perspective.

A comprehensive bibliometric analysis was conducted on the initial dataset obtained from Scopus, employing Biblioshiny within the R programming environment [16]. This analysis yielded key metrics including trends in publication, citation patterns, and the geographical distribution of research efforts. This provided an overarching view of the influence and development of AI and ML applications in resolving cognitive challenges in robotics.

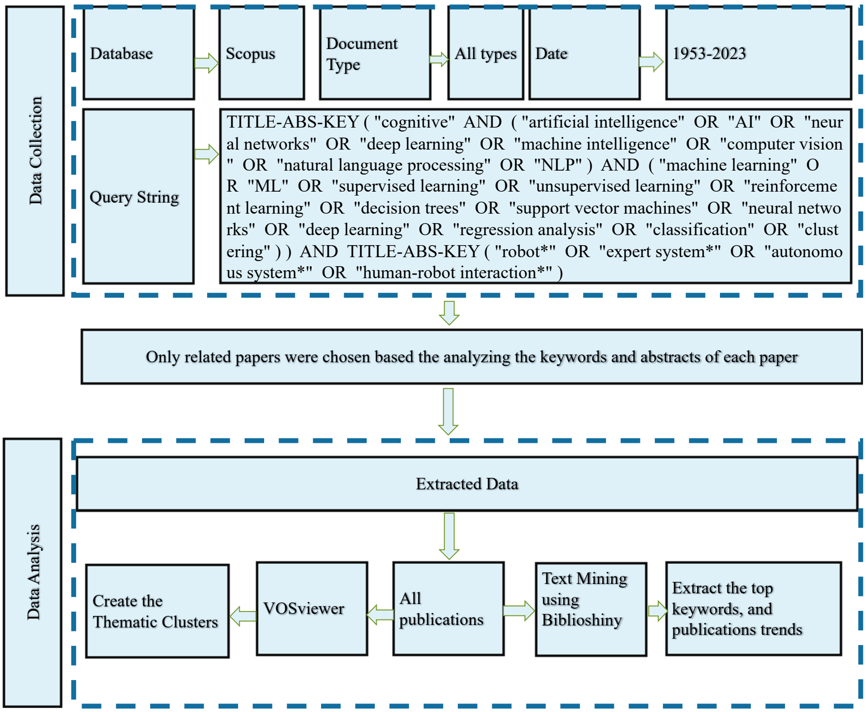

Fig. 1 The research methodology

Text mining techniques were employed using tools such as VOSviewer [21–23]. This methodology enabled the extraction of thematic trends, research trajectories, and emerging innovations in the application of AI and ML to cognitive aspects of robotics. It also facilitated the visualization of collaboration networks, highlighting significant researchers, institutions, and the evolution of joint research in this specialized area.

For presenting the findings, sophisticated data visualization tools, specifically VOSviewer and the Biblioshiny package, were utilized. These tools adeptly transformed complex datasets into clear, insightful visual representations, enabling the elucidation of significant conclusions regarding the use of AI and ML in overcoming cognitive hurdles in robotics.

The methodology was meticulously designed to align with the highest standards of bibliometric research, aiming to provide invaluable insights to a diverse audience, including academics, researchers, and policymakers in the field of robotics.

Additionally, the study explored the citation network of the gathered literature. This exploration aimed to identify key works, influential authors, and major research clusters within the field, enhancing the understanding of foundational theories and current discussions in the application of AI and ML to cognitive problems in robotics.

Beyond analyzing predefined keywords, an extensive co-occurrence analysis of author-assigned keywords was undertaken. This approach revealed underlying themes and conceptual connections, offering a more detailed perspective on the complexities of research in applying AI and ML to solve cognitive challenges in robotics.

A temporal analysis of research themes was also performed. By categorizing publications into distinct time periods, the study examined evolving trends, paradigm shifts, and new focal areas, adding depth to the understanding of how AI and ML have been applied to cognitive issues in robotics over time.

Recognizing the inherently interdisciplinary nature of this research, the study assessed the cross-disciplinary impact of the identified publications. This involved mapping the distribution of publications across different scientific disciplines, highlighting areas of cross-field collaboration and integration. This analysis contributed to a comprehensive view of the intersections between AI, ML, and cognitive challenges in robotics.

This expanded methodology, with its array of diverse analytical techniques, ensures a thorough and accurate exploration of how AI and ML are applied to address cognitive challenges in robotics. This multifaceted approach is designed to significantly contribute to the evolving landscape of interdisciplinary research in robotics.

3 Results and Discussion

The bibliometric analysis conducted using Biblioshiny provides a comprehensive view of the research field from 1953 to 2023, revealing several key insights about its development and current state. The involvement of 1037 sources, including journals, books, and other mediums, indicates a diverse and interdisciplinary nature of the field. This variety not only suggests a broad appeal across various disciplines but also reflects the richness of the research area.

The production of 2,261 documents in this period underscores the extensive research activity in the field, demonstrating a solid knowledge base for evaluating current and future research. This volume reflects a robust foundation, with a steady growth rate of 3.43% annually, indicating a field that is consistently expanding and building on previous work. The average document age of 9.53 years indicates the field's maturity, essential for ensuring new research is well- integrated within an established framework, allowing time for the academic community to absorb, critique, and expand upon it. Additionally, the average citation rate of 15.12 per document highlights significant academic engagement and impact, suggesting the field's output is not only widely read but also influential in furthering research and discussions, affirming its relevance and significance.

The exported, shown in Fig. 2, data tracing the number of articles published annually from 1953 to 2023 narrates the captivating evolution of a research field from its inception to its current state of active engagement. This longitudinal analysis reveals much about the field's development, interest, and scholarly output over time.

The journey commences modestly in 1953 with a single article, followed by a prolonged period of dormancy stretching up to 1970. This initial phase suggests the field's nascent state or a lack of distinct recognition as an independent area of inquiry. The absence of publications during these early years possibly points to limitations in technological capabilities or theoretical frameworks essential for advancing research in this area.

A gradual yet noticeable increase in publications starts in the mid-1980s, marking the beginning of more consistent academic attention. This slow but steady rise

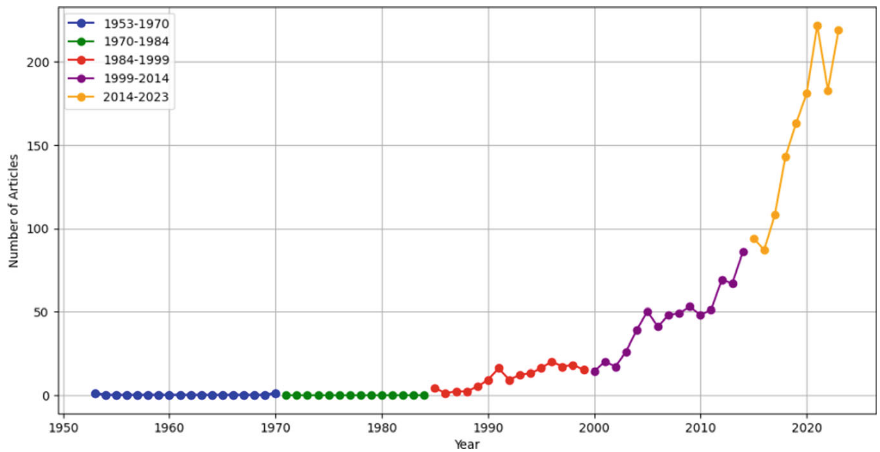

Fig. 2 Number of articles by year with different periods highlighted

through the 1980s and early 1990s hints at a growing interest, possibly spurred by advancements in related fields, making research more feasible and relevant.

The late 1990s and early 2000s witness a more significant surge in the number of publications. This uptick likely reflects various factors, including technological progress, increased funding opportunities, and the establishment of the field as a critical area of academic and research endeavour. Particularly noteworthy is the period from 2015 to 2023, which sees an exponential increase in publications, indicating heightened interest and active engagement in the field. The last decade, in particular, is characterized by the highest concentration of research activity, with the number of articles consistently surpassing the hundred mark each year. This sustained focus suggests the field's maturity, its critical importance, and its applicability to contemporary technological and societal challenges.

However, the data also shows fluctuations in publication numbers across different years. These variations might be influenced by external factors, including shifts in research funding, changing academic and industry priorities, or global events that impact research trajectories and resource allocation.

The growth of the relevant field is evidenced by the increasing volume of publications, which reflects the field's shift from obscurity to rapid development and sustained scholarly work. This trend testifies to the increasing importance of this field as well as its solid position in the academia and the research circles, characterizing a lively area of studies with an active contributing research community. The analysis of these trends' determinants could lead to more detailed understanding of the history of the field and its possible future evolution.

The integration of AI and ML in the development of cognitive capabilities in robots represents a pivotal advancement in the field of robotics, as underscored by the bibliometric analysis using VOSviewer, shown Fig. 3. This integration, spanning over several decades, has led to significant breakthroughs, shaping the role of robots in various sectors and fundamentally altering our understanding of machine capabilities.

AI and ML have been instrumental in enabling robots to process vast amounts of data, interpret sensory inputs, and make autonomous decisions. This capability is vital in environments where adaptability and responsiveness are crucial. In cognitive robotics, AI algorithms empower robots to perceive their surroundings in a human-like manner, using data from cameras, microphones, and sensors. This development has been particularly impactful in areas requiring high precision and adaptability, such as healthcare and manufacturing [24–26].

The application of ML in robotics has brought about a paradigm shift in how machines learn and adapt. Through techniques like deep learning and reinforcement learning, robots can now learn from their environment, adapt to new tasks, and improve their performance over time. This learning capability is particularly significant in dynamic environments where pre-programmed instructions are insufficient. For instance, in autonomous vehicles, ML enables real-time processing of traffic data, pedestrian movements, and road conditions, allowing for safer and more efficient navigation [27–29].

The VOSviewer analysis highlights the growing focus on human–robot interaction (HRI) [30, 31]. As robots become more prevalent in everyday settings, the ability

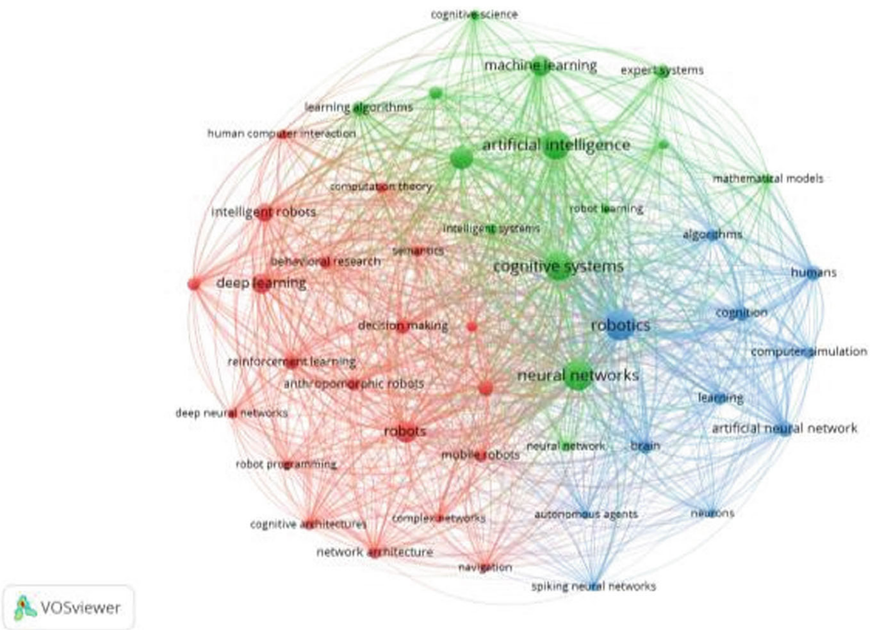

Fig. 3 Thematic clusters of top keywords

to interact seamlessly with humans has become increasingly important. AI and ML contribute to this by enabling robots to understand and respond to human emotions, gestures, and speech. This advancement is not only enhancing the user experience in personal and professional settings but is also opening new avenues in sectors like education, where robots can provide personalized learning experiences.

Another significant area of AI and ML application in cognitive robotics is decision-making [5, 30, 32]. Robots equipped with AI algorithms can analyze data, weigh options, and make informed decisions. This ability is crucial in scenarios where human intervention is limited or impractical, such as deep-sea exploration or space missions. AI-driven decision-making enhances the autonomy of robots, allowing them to perform complex tasks with minimal human oversight.

The VOSviewer bibliometric analysis gives a holistic picture of the cognitive robotics, AI, and ML research scenario highlighting related themes, dominant areas, and interdisciplinary integration. It highlights an important role which will be played by artificial intelligence and neural networks, with cognitive systems and deep learning emerging as the main engines of the further development, representing a movement towards robots with advanced cognitive properties. The study shows the interdisciplinary character of the field presenting the union of technical and biological sciences, with the relation between machine learning and cognitive science. The focus on anthropomorphic robots and human–robot interaction are examples of such shift toward user-centric design for more natural interactions. Further, it outlines new territories for innovation, such as deep and spiking neural networks and autonomy, mobility, and adaptability in robot applications. This overview proposes a research trend focused on advancing cognitive functions in robotics and emphasizes the importance of cross- disciplinary research and creation of more sophisticated, versatile, and user- centered robotic systems. Besides, it emphasizes the revolutionary role of AI and ML in extending the applications of robots and the underlying regulatory, privacy, and ethical issues as robots acquire autonomy.

4 Conclusion

This detailed bibliometric analysis aimed to trace the evolution and current landscape of research in cognitive robotics, artificial intelligence (AI), and machine learning (ML) from 1953 to 2023, revealing a steady and significant rise in academic engagement starting in the mid-1980s and a marked increase in publications in the late 1990s. The past decade highlighted the field's maturation and its escalating relevance in addressing contemporary technological challenges, alongside a growing emphasis on human-centric design, indicating a shift towards more sophisticated, user-oriented research. The study not only suggested broadening future research to include more diverse databases and qualitative analyses for a comprehensive understanding but also highlighted the importance of ethical considerations and user-centric designs in developing new technologies. In summary, this bibliometric analysis provides a foundational perspective on the cognitive robotics, AI, and ML research landscape, emphasizing its historical context, present state, and future pathways, offering valuable insights for both academic research and policy and practice in this rapidly advancing field.

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