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Knowledge domain analysis of artificial intelligence in automation and control systems

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This study mainly explores the evolution in the subject development of artificial intelligence documents in the field of automation and control systems from 1956 to 2019. Based on the search in WoS SCIE database, 27,782 documents are revealed. The VOSviewer is then employed to draw the co-citation network diagram. Moreover, both VOSviewer and Citespace are used to draw the keyword co-occurrence network diagram and the burst word change diagram from 2000 to 2019 to master the field trend. The results from the keyword co-occurrence reveal that "neural network" and "adaptive control" are the main keywords in all periods and after 2010 , the research topics has shifted to "adaptive control", especially in Lyapunov method, nonlinear control system, control system synthesis and multi-agent system. The overall document co-citation network can be roughly divided into two research axes: "adaptive control" and "nonlinear system". In terms of author co-citation, Ge, Shuzhi Sam, Li, Zhijun, He, Wei are the most commonly cited high-productivity authors, while Lewis, Frank L. is at the center of the whole co-citation network and plays a leading role in the field. In terms of journal co-citation, *Automatica and IEEE Transactions on Automatic Control* are most often cited together with other journals, and the link strength between the two is strong. These two journals are of small number but high-quality publications. *IEEE Transactions on Industrial Electronics* is at the center of the co-citation network, which shows its multidisciplinary nature.

Keywords: *Automation and control systems, Artificial intelligence, AI, Knowledge domain analysis, Informetric, Visualization analysis, VOSviewer, CiteSpace.*

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1. Introduction

In 2014, physicist Stephen Hawking said, "The development of full artificial intelligence could spell the end of the human race" [1]. According to the research report *Preparing for the Future of Artificial Intelligence* published by the White House, with the continuous development of artificial intelligence systems, man-machine cooperation will become an important development trend in the future society [2]. When machine learning is incorporated into the workflow, many new works will be generated. Stanford University started a century research on artificial intelligence (AI) in 2014. In the *Artificial Intelligence and Life in 2030* report, it is pointed out that various applications of AI are no longer purely technical research [3]. Instead, they are closely related to the life of human beings. For example, the smart city is one of the applications that many countries have paid attention to in recent years. It uses information and communication technology to achieve the goal of more economical and effective urban governance. For example, automatic systems are adopted to control or change lanes according to traffic flow, parking or signal management.

Qiu suggested that AI is related to automation to a certain extent, as AI, especially robots, often need components of automation, and from machines to robots to AI, are several stages of machine development [4]. In the field of automatic control, the introduction of AI forms intelligent control, which solves many problems of industrial automatic control systems, improves the operation efficiency of automation, and avoids the influence of external interference factors. Besides, AI also improves the control accuracy and product quality, reduces costs and energy, and makes production safer and more reliable. Sarter, Woods and Billings mentioned that automation reduces human intervention and human error [5]. Human beings monitor this new type of automation and serve as an automatic resource manager. However, they pointed out that even highly automated systems still require the participation of operators, thus requiring communication and coordination between people and machines, while most machines designed to be accurate and powerful do not have such communication capabilities.

From a study of Google Books [6], the Ngram Viewer database developed by Google was adopted for search with five words including automation, AI, robotic, deep learning and machine learning from 1956 (the year when the term "Artificial intelligence (AI)" just appeared) to 2008. The evolution in automation and AI in the past century are roughly the same, which shows that there must be a certain degree of correlation between the two subjects in the overall development trend.

The past two decades have witnessed significant advances on informetrics or knowledge map analysis of AI or AI application research. Zhao and Lai took journal documents as the main body, conducted visual analysis on the research front in the field of AI, and opened the subsequent quantitative research on artificial intelligence in related fields such as robots, machine learning, big data, etc [7]. The concept of research front was first put forward by Price. The research front refers to the achievements and novel concepts that are in the leading position in each subject field and are widely cited by experts in the field at a particular time [8]. Therefore, the relevant studies of research front begins with

highly cited documents in a specific field, and then the co-citation relationship is disclosed [9]. In addition, the co-occurrence analysis is also an important tool for studying research front. It can discover research hotspots in the research field, analyze the evolving process of disciplines in the field horizontally and vertically, and the relationship between fields or disciplines, and reflect the scientific research level of a certain specialty and the dynamic and static structure of its development history [10] .

In 2019, the *Artificial Intelligence Index Report 2019*, published by the Stanford University Human-Centered Artificial Intelligence Institute (HAI), collected bibliographic data on AI topics worldwide from Microsoft Academic Graph (MAG), arXiv and Scopus databases from 1998 to 2018, including journal documents, conference documents and patents for comparative analysis. The results shows the AI documents are mainly distributed in the domain of machine learning, natural language processing, and computer vision and they are extensively discussed. Additionally, startups are leveraging AI technologies in the development of products, specifically in the areas of data tools, fashion&retail technology, and automation [11].

In 2018, China published the *China Artificial Intelligence Development Report 2018*, which analyzed the growth of 1.87 million documents and patents in the field of AI, the co-author relationship network of various countries, and the co-occurrence of keywords, so as to understand the current research front and make strategic layout [12]. The report pointed out that the global document output in the field of artificial intelligence entered the growth track in the early 1990s. It also revealed that in recent years, the highly cited documents of AI in the world are mainly oriented to deep learning, neural networks, big data, etc.

The visualization analysis tools, e.g., CiteSpace, VOSviewer, Google Earth have been exercised in the informetric study for drawing knowledge map in many fields for a few years. Peng and Ye [13] conducted a bibliographic analysis of "artificial intelligence" retrieving 4,736 documents from 1991 to 2013 based on WoS database, then utilized CiteSpace to create a knowledge map and performed co-citation analysis, identifying three kernel articles which are: genetic algorithms, Bayesian networks, and fuzzy theory. These findings highlight the significance of these three techniques as important foundations for the development of artificial intelligence during the period [13]. Zhao et al [7], with the aim of providing a more developmental plan for smart cities, screened 2,920 documents from WOS, used VOSviewer and CiteSpace to conduct document analysis and research in this field, and carried out comprehensive scientific econometric analysis and knowledge mapping in terms of diversity, time division and dynamics. Through co-citation analysis, they found that the main research topics can be divided into three fields: "the concepts and elements of the smart city", "the smart city and the IoT" and "the smart city of the future". They also carried out keyword co-occurrence analysis and found that the research fronts of smart cities are "urban-development, sustainable cities, cloud computing, AI and integration" [14].

The above brief literature review reveals that although the informetric analysis in AI or AI application research is quite diverse, there has not been any informetric research in automation and control system, which is closely related to AI. In light of such research

gap and the importance of AI, this study intends to analyze the development trend of AI research in the field of automation and control system from the perspective of informetrics. This study searched the keywords related to AI in the automation and control system documents in the Science Citation Index Expanded (SCIE), a sub-database of the Web of Science (WoS) published by Clarivate Analytics, analyzed the contents of bibliographic data fields, and then drew a knowledge map to explore the research front and comprehensively observe the overall development of AI research in the field of automation and control system.

This study aims to provide an overview of AI in automation and control system, based on knowledge domain analysis, include the knowledge base of this topic, the distribution of co-occurrence words in the author's keywords, the research frontier evolution through analysis of document co-citation, author co-citation and journal co-citation as well.

Research Method

This study adopted the research method of informetrics to explore the research front in the field of AI in automation and control systems. The WoS SCIE database was adapted to retrieve relevant bibliographic data. Then, ten bibliographic data fields including title, author's full name, title of the journal, date of publication, number of references, author's keywords, research fields, references, author's institution and author's country, were used as variables to analyze the productivity of AI documents in the field of automation and control system. Conducting productivity analysis is considered a prerequisite as it serves as the foundation to enable precise analysis of the research front in this area. Moreover, VOSviewer and CiteSpace analysis tools were employed to establish co-occurrence analysis of author keywords, and to draw knowledge maps in combination with co-citation research of documents, authors and journals, so as to explore the current research front.

Data Retrival

As the term "artificial intelligence (AI)" first appeared in 1956, the retrieval period for the WoS SCIE database was set from 1956 to 2019. The data type was limited to "article" and the domain was automation and control systems. To develop a retrieval strategy, the terms related to artificial intelligence (AI) should be first selected. This study referred to the subject terms of Academic Search Complete database in EBSCOhost database platform, used the term "Artificial Intelligence" for retrieval, and viewed the narrow terms by using the Thesaurus function. Based on the document discussion data, terms such as "Machine Learning", "Neural Network", "Expert System" and "Robot" were selected in addition to "Artificial Intelligence/AI". Thus, the retrieval terms determined include: "Artificial Intelligence", "AI", "Machine Learning", "Deep Learning", "Neural Network", "Expert System" and "Robot". Consequently, the retrieval strings were set as follows: TS=(artificial intelligence*) OR TS=(AI) OR TS= (deep learning) OR TS=(machine learning)OR TS=(neural network*) OR TS=(expert system*) OR TS=(robot*).

Where the symbol "*" indicates truncation. TS is the abbreviation of topic search, which means that the retrieval field is limited to the following topics: title, abstract and author's keywords of the article. The above string was used to retrieve the relevant list of artificial intelligence (AI), then the field was further limited to automation and control systems, the time range was set to 1956-2019 and "article" is the sole type of publications been chosen. Thus, the complete retrieval strategy of this study was formed.

Tools and Data Verification

This study retrieved and downloaded the complete bibliographic data and cited references of AI documents in automation and control systems from the WoS SCIE database. These data were then exported into text files, transferred to Excel spreadsheet software, and analyzed to obtain relevant research results. Moreover, VOSviewer and CiteSpace5.7 R2 visualization analysis software were employed to carry out subject burst words, co-occurrence words and co-citation analysis of bibliographic data such as author's keywords, document titles, journal titles, author's full names, author's institutions and countries, and references.

Some of these data need to be verified caarefully. Due to many changes after the database was built, it is necessary to further compare and verify the data manually, such as changes of journal titles, mergers of journals, suspension of journals, etc. In addition, the author names and institution names should be proofread one by one to obtain correct bibliographic files and ensure the accuracy of analysis results.

In particular, the four parts of data verification are described as follows. For the author productivity, the bibliographic data of the author full-name field (WoS code is AF, representing author full name) in WoS downloaded were used to verify the data with the same name and surname. For example, the author Ge. Shuzhi Sam has different descriptions as: Ge, S.S., Ge, SS, Ge, Shuzhi S., Ge, SZS and Sam Ge, Shuzhi, which were then treated as Ge Shuzhi Sam after verification with the affiliation. After data verification, 27,782 documents and 51,189 unique authors were obtained. Regarding with the journal productivity, the "publication name" (WoS code is SO) in the downloaded bibliographic data field was firstly analyzed, and each publication was verified in the Ulrich's Web database one by one. The journal name was verified according to the "title history details" field in the database, and the total articles of individual journal was calculated with the latest journal title. A total of 27,782 documents were distributed in 83 journals.

Results and Discussion

The retrieval in this study resulted in 27,782 bibliographical data in 83 journals in March 2020 and the research front in the field of AI in automation and control systems can be investigated. As indicated earlier, the VosViewer and CiteSpace were used to analyze the co-occurrence of authors' keywords, the trend changes of burst words, the document co-citation, the author co-citation and the journal co-citation, and the changes in theme trend and knowledge maps of AI documents in the field of automation and control systems were

obtained. In order to show the evolution of the concept of AI over the years, this session will present the research results from keyword co-occurrence and co-citation analysis. Co-citation analysis includes document co-citation, author co-citation and journal co-citation.

Keyword co-occurrence analysis

In this study, the bibliographic data of the downloaded AI documents in the field of automation and control systems was verified and processed, and the keywords of the same concept were unified in the author keyword (WoS field code is DE, which represents Author keyword). For example, the keywords containing robots or robot were unified into robot. Then, bibliographic data of 27,782 artificial intelligence documents were imported into VOSviewer and a limit of "minimum number of occurrences of a keyword" of 100 times was set. Then, 93 author keywords with high frequency were screened out, sorted according to total link strength, and the first 20 keyword clustering analysis including cluster and occurrence data were identified. "Neural networks" is the keyword with the strongest total link strength and the most occurrence times, followed by "adaptive control", as illustrated in Appendix I.

According to the keyword clustering analysis, Figure 1 illustrates the co-occurrence word network of the author's keywords. In the Figure, the four clusters in the appendix I are respectively represented by cluster 1 to cluster 4 in red, blue, green and yellow. The size of the circle indicates the total link strength of the keyword, while the thickness of the line between the two circles relfects the number of links between the two points.

Figure 1 clearly shows that the link strength between "neural network" and "adaptive control" is the strongest, while "nonlinear system" has a strong link with the two. This shows that in the field of automation and control systems, the documents on AI is mainly based on "nonlinear systems" that apply the concepts of "neural network" and "adaptive control". This differs from the primary themes of the 1990s, as revealed in the *Artificial*

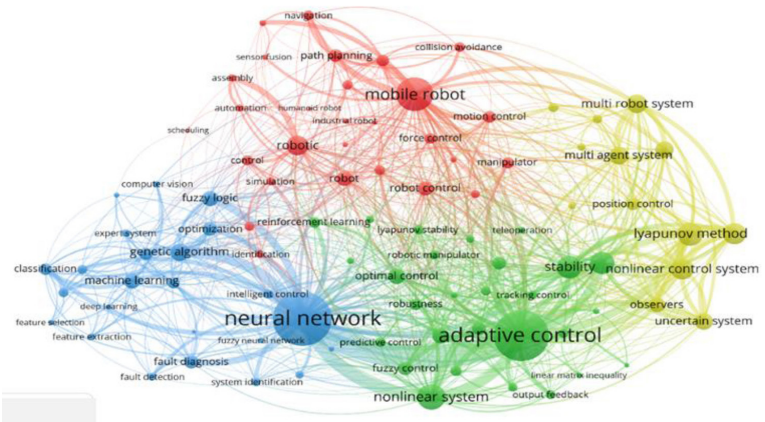


Figure 1

Keyword Co-occurrence Network of of AI Documents in Automation and Control Systems

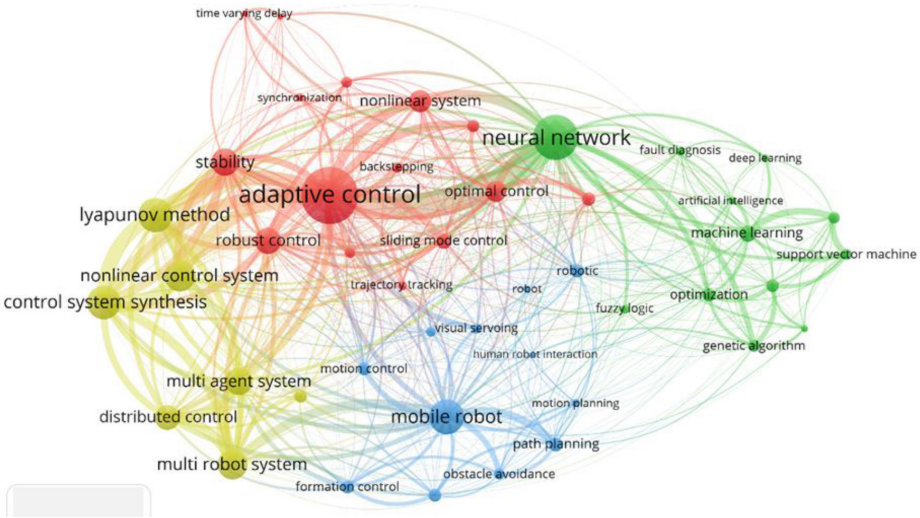


Figure 2

Keyword Co-occurrence Network for the Period from 2010-2019

Intelligence Development Report (CISTP 2018), which emphasized "deep learning," "neural networks," and "big data" through keyword co-occurrence analysis.

This study further explores the evolving process of artificial intelligence. The third wave of AI from 2010 to the present due to the development of machine learning is examined by dividing the publications into two time periods from 1956 to 2009 and from 2010 to 2019. This results in 11,812 and 15,970 documents, respectively, for the two time periods. The co-occurrence analysis of author keywords in AI documents in the field of automation and control systems was conducted. It is found that the keywords on the theme of "Robot" cannot form a cluster before 2010. Comparing the keyword co-occurrence networks before and after 2010 reveals that researchers have shifted their focus from "neural network" to "adaptive control", while keywords in this cluster, such as Lyapunov method, nonlinear control system, control system synthesis, multi-agent system have become the research fronts of AI in the field of automation and control systems, as shown in Figure 2.

In addition to the co-occurrence analysis of keywords, the analysis of burst words can supplement the research hotspots of this research topic at different time intervals. Since the research topics of the documents before 2000 are too scattered to identify the research hotspots, the scope of the documents was extended to the period between 2000 and 2019. Then the burst words were analyzed by CiteSpace software. The analysis shows obvious changes, as shown in Figure 3. Keywords such as "neural network", "fuzzy logic", "robotic" and "assembly" appeared between 2000 and 2001, but they disappear after 2008. However, the concepts related to "control component" or "control system" were widely proposed after 2015, such as "nonlinear control system", "neurocontroller", "closes loop system" and "series elastic actuator". Moreover, by analyzing the above-mentioned co-

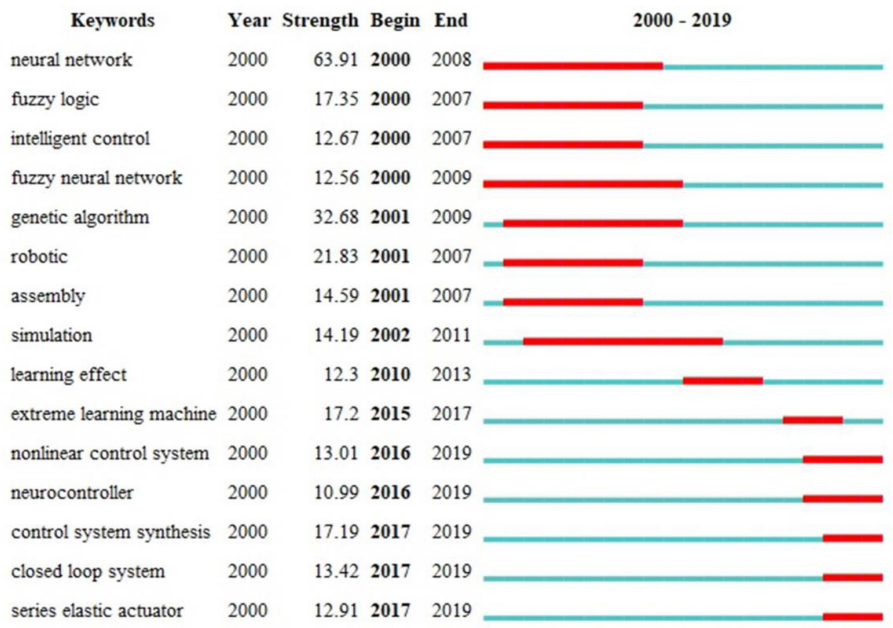


Figure 3

Top 15 Burst Words in AI Documents in Automation and Control Systems from 2000 to 2019 (red line indicates the beginning and the end of the occurrence period)

occurrence words, one can know that the concepts such as "neural network", "fuzzy logic" and "robotic" are the theoretical framework basis of automation and control systems. Over time, the output of new technologies and control components enables the automatic control system to continuously progress.

Co-citation analysis

Co-citation analysis classifies important documents in a discipline by distance, and then outlines the knowledge structure with uneven density to visualize them. Clusters can represent subject areas, basic concepts or theories. The similarity between clusters can present the model, core theory and extended concept of discipline field, and can also be used to explore the division and regeneration of discipline field. It can also observe the research focus, structural characteristics, development and evolution of discipline field, and the similarity degree between disciplines, and then define the research front [15][16]. What follows outline the development of this research front from document co-citation, author co-citation and journal co-citation to reveal the trend change of AI domain.

Document co-citation. In the part of document co-citation analysis, the bibliography of AI documents in the field of automation and control systems is merged into VosViewer, and the "minimum number of citations of a cited reference" is set as 100 times. The 143 documents obtained can be divided into 5 clusters according to the total link strength,

and the first 20 documents can be sorted out (refer to Appendix II). There is no document belonging to Cluster 5 in the first 20 documents. This shows that the overall link strength of the cluster is relatively weak. The most cited document with the strongest total link strength is "Applied Nonlinear Control" by Slotine, J. and Li, W. [17]. The document "Identification and Control of Dynamical Systems Using Neural Networks", published by Kumpati, S. Narendra, and Parthasarathy Kannan [18] in *IEEE Transactions on Neural Networks*, ranked second, mainly proves that neural networks can be effectively used for identification and control of nonlinear dynamical systems. The article "Gaussian Networks for Direct Adaptive Control" published by Sanner, R. M. and Slotine, J. is ranked third [19]. In this article, an adaptive tracking control structure using the Gaussian radial basis function,which is often used in support vector machines in machine learning, was proposed and evaluated for a continuous-time nonlinear dynamical system, and a stable weight adjustment mechanism was determined using the Lyapunov theory.

The results are presented as visual graphs, with red, green, blue, yellow and purple representing cluster 1 to cluster 5, as shown in Figure 4. The figure indicates that green (cluster 2) and blue (cluster 3) are outstanding. The cluster 2 is headed by "Nonlinear and Adaptive ControlDesign" by Krstic, M., 1995 and Gaussian Networks for Direct Adaptive Control by Sanner R. M, focusing mainly on "Adaptive Control". Cluster 3 is headed by Applied Nonlinear Control by Slotine, J., 1991 and Nonlinear Systems by Khalil, H. K., 2022, focusing on "Nonlinear Systems and Control". These two clusters enbale revealing the discipline structure in this network diagram.

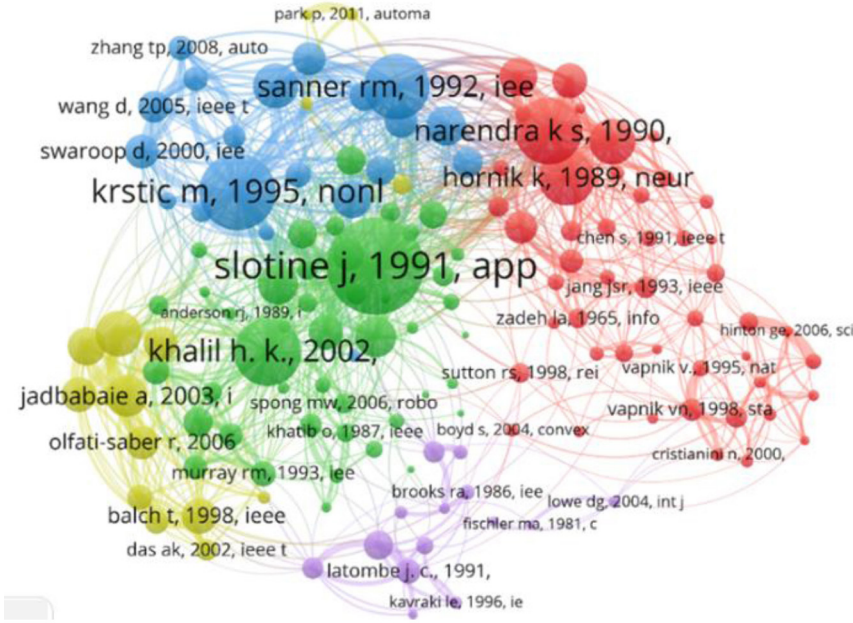


Figure 4

Documents Co-citation Network of AI in Automation and Control Systems

Based on the document co-citation analysis conducted in this study, the top three strong linkages documents are related to topic of "adaptive control" and " nonlinear control". This finding differs from the themes of Peng's research, which are genetic algorithms, Bayesian networks, and fuzzy theory demonstrating the evolvement of research topics in the field of automation and control system over time.

Author co-citation. In the analysis of author co-citation, the parameter was set at minimum number of citations of an author of 500 times, and the 55 authors identified can be divided into 4 clusters according to the total link strength. The top 20 authors are listed in Appendix III. Ge, Shuzhi Sam; Liu, Yanju; Tong, Shaocheng; He, Wei; Li, Yangmin are ranked in a descending order in terms of total link strength and all the 5 authors were in the author group of cluster 4. This shows the strong link strength in the cluster.

Indeed, the visual diagram of Figure 5, illustrating red, green, blue, yellow corresponding to cluster 1 to 4, shows that the overall total link strength of yellow (cluster 4) is relatively strong, including Ge, Shuzhi Sam; Li, Zhijun; He, Wei, who appeared in the Appenix III with high citations. The main research field of Dr. Ge, Shuzhi Sam are adaptive control, intelligent systems and artificial intelligence. (https://cde.nus.edu.sg/ece/staff/ge-shuzhi-sam/) ; Dr. Li, Zhijun's main research fields are theoretical and applied research on wearable robots and vital power systems.(https://en.auto.ustc.edu.cn/2021/0616/c26828a513171/page.htm); Dr. He, Wei's research areas are flexible robot control, flapping-wing flying robot, intelligent control and distributed parameter system control (https://ensaee.ustb.edu.cn/facultystaf/overview/znkxyjzx/10626253.htm). These three scholars are coauthors for publications focusing on robot-related research.

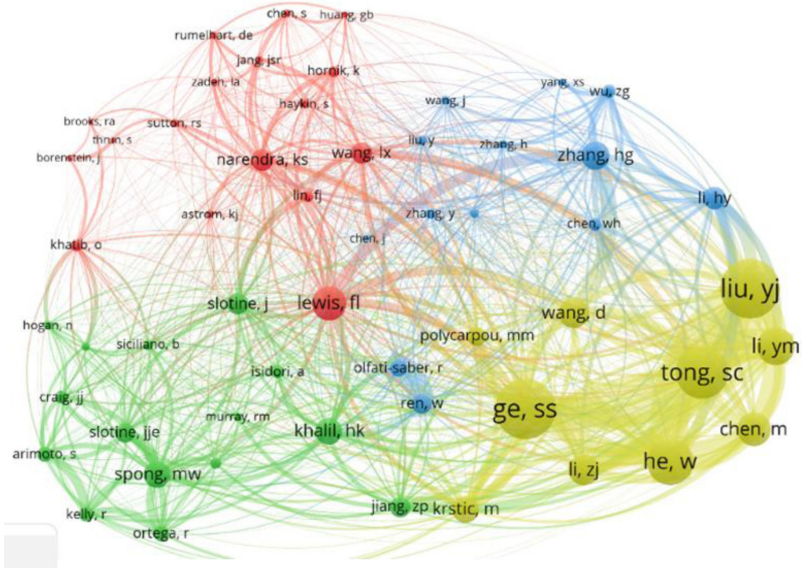


Figure 5

Author Co-citation Network of AI Documents in Automation and Control Systems

On the other hand, Tong, Shaocheng, Liu, Yanjun and Li, Yongming, who also belong to the same yellow cluster. They are of strong co-citation relationship with total link strength. Thus, the circle size in the figure is more prominent.The above observation suggests that the author co-citation network diagram not only shows the influence of authors in the field, but also may correspond to high-productivity authors and reveal the co-author relationship to a certain extent.

Significantly, Figure 5 indicates that Dr. Lewis Frank L. of the Department of Electrical Engineering of the University of Texas Arlington is linked to each of the four clusters. Dr. Lewis has studied automation and control for more than 4 decades mainly focusing on motor electronics and automation and control, as well as the application of neural network-like systems. (https://mentis.uta.edu/explore/profile/dr-frank-lewis) Due to his long and extensive research on the subject of AI in automation and control systems, Dr. Lewis Frank L. has become the center point of the whole research network.

Journal co-citation. In the journal co-citation analysis, the parameter of the minimum number of citations of a source is set at 1,000 times and the 98 journals identified can be grouped into four clusters according to the total link strength, and the list of 20 journals is sorted, as shown in Appendix IV. The results are drawn into a journal co-citation network diagram in red, green, blue and yellow corresponding to cluster 1 to cluster 4, respectively (see Figure 6). The figure indicates that blue, yellow and green have high clustering degree, but red (cluster 1) has low clustering degree. Although *Automatica* and *IEEE Transactions on Automatic Control* belong to different clusters, they are close to each other and their corresponding points are big, which shows that their published documents are often cited

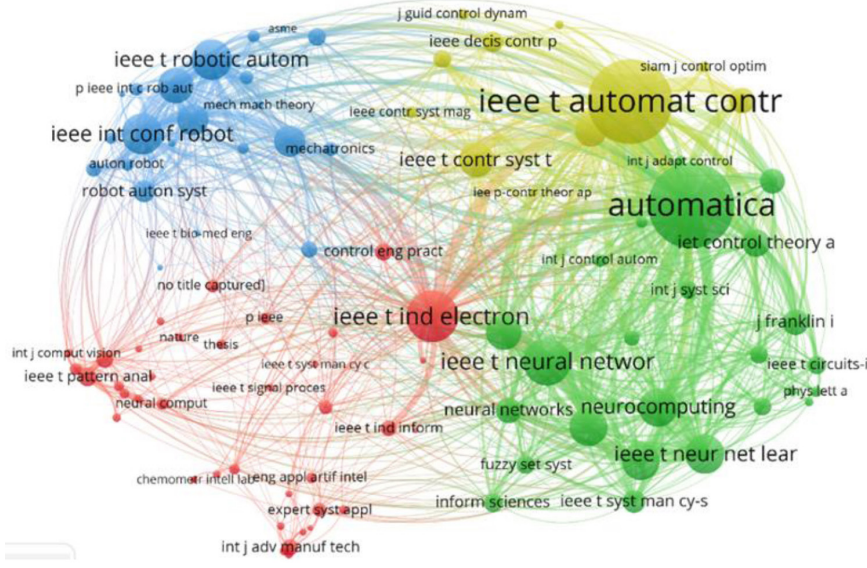


Figure 6

Journal Co-citation Network of AI Documents in Automation and Control Systems

together. It is worth noting that the above two journals are not listed in the top 12 with high productivity journals, which means that their publication volume is small but of high quality. *IEEE Transactions on Industrial Electronics* is at the center of the whole co-citation network, showing that it covers multiple topics.

Automatica is primarily focuses on research in the field of automatic control [20]. It is applicable to various aspects include industrial automation, robotics technology, adaptive control and intelligenc computing. *IEEE Transactions on Automatic Control*, as one of the official journals of the IEEE Control Systems Society, it is considered one of the top journals in the field of automatic control,which is applied to control theory and methods, system modeling and identification and control system design [21].

Significantly, *IEEE Transactions on Industrial Electronics* (2023) appears in the center of the network diagram [22]. As the journal is cited together with different journals in other clusters, the topics published in the journal are of a relatively wide scope. It covers the topics of electronics, control and communication, instruments and intelligent computing. The journal also accepts manuscripts in industrial and manufacturing systems and processes, including system control, signal processing, robots, neural networks and factory automation.

Conclusions

This study employed the methodology of informetrics to explore the research front of AI documents in the field of automation and control systems from 1956 to 2019. The study analyzed 27,782 records of related documents searched from the WOS SCIE. The following conclusions may be drawn from the results of this study.

The keyword co-occurrence network diagram revealed that “neural network” and “adaptive control” are the main keywords in all periods and the connection strength of the two is strong. Comparing the keyword co-occurrence network diagrams before and after 2010, it can be found that researchers have shifted their focus from “neural network” to “adaptive control”, such as Lyapunov method, nonlinear control system, control system synthesis, multi-agent system, etc. Moreover, burst words emerged after 2015 are “nonlinear control systems”, “neurocontroller”, “closes loop system” and “series elastic actuator”.

The research front analysis reveals the evolving trend of document co-citation, author co-citation and journal co-citation of AI topics in the field of automation and control systems. From the research results, the document co-citation network can be roughly divided into two research axes: “adaptive control” and “nonlinear system”. The author co-citation analysis reveals that the top three authors with strong linkage focus on robot-related research. The analyses of journal co-citation indicate that *Automatica, IEEE Transactions on Automatic Control,* and *IEEE Transactions on Industrial Electronics*, which primarily focus on the research topics of automatic control, control system applications, and system modeling and identification, serve as the prominent platforms for scholarly research.

This study, based on informetrics, reveals the research front of AI documents in the field of automation and control systems. By examining the research front, this study sheds light on the innovative studies that have emerged in this field, enabling researchers to keep up-to-date with the latest advancements and developments. According to the research results, the strategies in various aspects of AI in the field of automation and control systems may be proposed to improve for deficiencies or invest more resources in advantageous research. It is suggested that the future studies may focus on productivity and influence of various leading reserach institutes and countries, including innovative patent analysis, to understand the layout of global AI research and applications.

Acknowledgment

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Appendix

Appendix I

Author Keyword Co-occurrence Analysis (the Top 20 by Link Strength)

Rank	Author keyword	Cluster	Occurrence	Link Strength
1	neural network	3	2,052	1,658
2	adaptive control	2	1,026	1,522
3	mobile robot	1	872	907
4	nonlinear system	2	451	633
5	Lyapunov method	4	194	561
6	Stability	2	327	537
7	robust control	2	322	530
8	control system synthesis	4	129	498
9	nonlinear control system	4	138	477
10	Robotic	1	605	453
11	multi robot system	4	180	411
12	multi agent system	4	272	385
13	genetic algorithm	3	386	376
14	distributed control	4	177	362
15	uncertain system	4	123	361
16	optimal control	2	274	334
17	sliding mode control	2	292	324
18	machine learning	3	476	323
19	fuzzy logic	3	283	317
20	Observers	4	100	302

Appendix II

Document Co-citation (the top 20 by Link Strength)

Rank	Literture	Cluster	Citations	Link Strength
1	Slotine J. (1991), 〈Applied Nonlinear Control〉	2	889	1798
2	Krstic M. (1995), 〈Nonlinear and Adaptive Control Design〉	3	480	1368
3	Khalil, H. K. (2002), 〈Nonlinear Systems, 3rd〉	2	640	1172
4	Narendra K. S. (1990), 〈Identification and Control of Dynamical Systems Using Neural Networks〉	1	496	1160
5	Sanner R. M. (1992),〈Gaussian Networks for Direct Adaptive Vontrol〉	3	330	1136
6	Hornik K. (1989), 〈Multilayer Feedforward Networks are Universal Approximators〉	1	407	947
7	Olfati-Saber R. (2004), 〈Consensus Problems in Networks of Agents with Switching Topology and Time-Delays〉	4	267	743
8	Cybenko G. (1989), 〈Approximation by superpositions of a sigmoidal function〉	1	286	734
9	Polycarpou M. M. (1996), 〈Stable Adaptive Neural Control Scheme for Nonlinear Systems〉	3	193	723
10	Jadbabaie A. (2003), 〈Coordination of Groups of Mobile Autonomous Agents Using Nearest Neighbor Rules〉	4	215	673
11	Spong M. W. (1989), 〈Robot Dynamics and Control〉	2	360	658
12	Khalil H. K. (1996), 〈Nonlinear Systems, 2nd〉	2	296	640
13	Wang L. X. (1994), 〈Adaptive Fuzzy Systems and Control: Design and Stability Analysis〉	3	266	629
14	Funahashi K. (1989), 〈On the Approximate Realization of Continuous Mappings by Neural Networks〉	1	178	600
15	Ren, W. (2005), 〈Consensus Seeking in Multiagent Systems under Dynamically Changing Interaction Topologies〉	4	186	594
16	Ioannou P. A. (1996), 〈Robust Adaptive Control〉	3	193	588
17	Balch T. (1998), 〈Behavior-Based Formation Control for Multirobot Teams〉	4	200	543
18	Fax J. A. (2004), 〈Information Flow and Cooperative Control of Vehicle Formations〉	4	148	540
19	Hunt K. J. (1992), 〈Neural Networks for Control Systems: a Survey〉	1	206	529
20	Slotine J. (1987), 〈Applied Nonlinear Control〉	2	250	529

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Appendix III

Author Co-citation (the Top 20 by Link Strength)

Rank	Author	Cluster	Citations	Link Strength
1	Ge, Shuzhi Sam	4	1617	9371
2	Liu, Yanjun	4	1047	9235
3	Tong, Shaocheng	4	1050	8118
4	He, Wei	4	986	7161
5	Li, Yangmin	4	779	5651
6	Lewis, Frank L.	1	1146	5125
7	Chen, Mou	4	632	5034
8	Li, Zhijun	4	701	4512
9	Wang, Duansong	4	788	4475
10	Zhang, Huaguang	3	840	4154
11	Khalil, H. K.	2	1202	3964
12	Krstic, M.	4	756	3962
13	Spong, M. W.	2	1403	3888
14	Li, Hongyi	3	555	3245
15	Narendra, K. S.	1	1137	3172
16	Slotine, J.	2	922	3077
17	Wang, Lixin	1	778	3072
18	Jiang, Zhongping	2	648	2962
19	Slotine, J.	2	856	2879
20	Ren, Wei	3	947	2844

Appendix IV

Journal Co-citation (the Top 20 by Link Strength)

Rank	Journal	Cluster	Citation	Link Strength
1	Automatica	2	21580	487021
2	IEEE Transactions on Automatic Control	4	24457	476347
3	IEEE Transactions on Industrial Electronics	1	14688	249707
4	IEEE Transactions on Neural Networks	2	11593	223634
5	IEEE International Conference on Robotics and Automation	3	12872	187920
6	IEEE Transactions on Robotics and Automation	3	13547	182147
7	IEEE Transactions on Neural Networks and Learning Systems	2	5486	171755

Contd...

8	IEEE Transactions on Fuzzy Systems	2	6823	170125
9	Neurocomputing	2	7208	169161
10	IEEE Transactions on Cybernetics	2	5368	167160
11	The International Journal of Robotics Research	3	10305	153386
12	IEEE Transactions on Systems, Man, and Cybernetics	2	6741	153186
13	IEEE Transactions on Control Systems Technology	4	6693	149424
14	International Journal of Control	4	6860	134177
15	IEEE-ASME Transactions on Mechatronics	3	7856	130164
16	IEEE Transactions on Robotics	3	6771	128231
17	IET Control Theory & Applications	2	4040	111937
18	Neural Networks	2	5523	101845
19	Systems & Control Letters	4	4231	100595
20	Journal of the Franklin Institute	2	3671	100182

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