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Review Paper

Research Trends in Utilizing Artificial Intelligence in Satellite-Based Internet of Things: A Scientometric Analysis

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ABSTRACT

Today, according to the development of satellite-based hybrid networks that are able to provide diverse and new services to most parts of the planet, the designers of such networks are encouraged to use new communication technologies such as the Internet of Things and artificial intelligence to improve the performance of such classes of networks. In this article, using scientometric tools, the status of scientific publications in the field of "utilizing AI in satellite-based IoT" has been investigated. For this purpose, more than 475 research documents published from 2013 to 2023 have been extracted from the Scopus database and accordingly evaluated and analyzed using software tools such as Bibexcel and VOSviewer. Based on the statistical results, China, India and North America are among the top performing countries in this field. In addition, based on our findings, the schemes namely machine learning, deep learning, reinforcement learning, neural networks and convolutional neural networks have been used the most, in this research domain.

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1. INTRODUCTION

The rapid proliferation of satellite technology and the advance of the Internet of things (IoT) have laid the groundwork for an interconnected world, where satellites act as pivotal facilitators for seamless communication and data exchange.

Deploying IoT devices in remote and inaccessible areas is often challenging due to limited infrastructure. Satellite-based IoT addresses this challenge by providing ubiquitous connectivity, enabling real-time data transmission across diverse environments.

Artificial Intelligence (AI), with its ability to process vast volumes of data and extract meaningful patterns, emerges as a critical enabler in enhancing the efficiency and effectiveness of satellite-based IoT systems.

Machine learning (ML) algorithms empower such systems to analyze and interpret data and optimize decisions for applications in precision agriculture, environmental monitoring, and disaster response.

Researchers such as in [1], emphasize the high potential of using deep neural networks (DNN) in handling complex data representations, aligning with the requirements of diverse satellite-based IoT applications. In [2], provide foundational insights into the principles of AI, laying the theoretical groundwork for its application in the context of satellite-based IoT.

As the synergy between AI and satellite-based IoT gains momentum, it becomes imperative to assess the current state of research and identify emerging trends. S.Bi and et.al in [3], examine three broad approaches including intelligent services, brilliant stability, and smart security in communication networks that use these two types of technology.

Today, due to satellite-based communication networks that are able to cover many people in different regions of the globe, it has become possible to expand communication networks based on IoT technology. The development process of its communication protocols has always faced a challenge that has been addressed in reference [4].

In addition, in order to create scalability in this type of communication network, it is recommended to use deep learning (DL) algorithms. In addition, the combination of two AI technologies and the IoT in satellite-based communication networks adds two special characteristics to the communication network. In such a way; AI leads to the ability of devices to learn, while IoT will lead to the interaction of devices with each other using the Internet. Of course, challenges such as the creation of space debris and their collision with each other are discussed in [5].

In [6], a solution has been proposed that improves the communication quality in a satellite network based on extended extreme learning machine (ELM) algorithms. To use this type of algorithm, IoT sensors have also been used to collect weather data. Notable contributions by scholars like [7] have significantly influenced the development of AI methodologies, fostering their integration into satellite-based IoT frameworks. Concurrently, research papers such as [8-11] offer a comprehensive survey of the existing literature, highlighting the evolving landscape and identifying gaps that warrant further investigation.

As the main contribution of our work, this paper aims to conduct a scientometric analysis to systematically review and synthesize the existing literature on the integration of AI in satellite-based IoT. By employing quantitative and qualitative methods, we seek to identify influential research clusters, key contributors, and evolving thematic trends.

Through this analysis, we aim to contribute to a deeper understanding of the intellectual landscape, offering insights that can guide future research directions and inform policy decisions. Therefore, the convergence of AI and satellite-based IoT presents a fertile ground for future innovations and explorations. This scientometric analysis sheds light on the intricate web of research endeavors in this domain, offering a nuanced understanding of the current state of knowledge and paving the way for future advancements in this transformative intersection of technology.

Scientometric analysis offers a systematic approach to mapping the intellectual structure of this multidisciplinary field, providing a comprehensive overview of research patterns, influential authors, and key thematic areas. Scientometrics is a tool that can measure some of the most important indicators of any research field, such as the trend of published scientific productions, leading countries, leading authors, leading institutions and universities and the frequency of key words or scientific concepts in a specific subject. In addition software tools such as

VOS viewer and Bibexcel can draw some relational networks such as co-words, co-countries, co-authorships and density of the used words.

In addition, it is possible to outline the way of cooperation between the leading countries in the field [8-10].

The rest of this paper is organized as follows. Section 2 describes the research background, data sources and methods used for the scientometric analysis. Section 3 presents the employed research methodologies. Section 4 presents the results and discussions of the given analysis, including publication trends, research networks, and research topics. Section 5 concludes the paper and recommends possible future research directions.

2. RESEARCH BACKGROUND

Due to the fact that in this domain, no scientometric work has been specifically examined or published, this idea has been thoroughly discussed in this article. The concept of IoT refers to objects that communicate and share data without human intervention.

Today, with the introduction of the concept of smart urban development based on the IoT, the need to create systems with the ability to measure and process processes automatically is felt more than in the past. In this regard, a scientific analysis from 2012 to 2021 based on the SCOPUS database has been presented in [12], all kinds of smart solutions for farmers and other influential factors investigated. The results of this research show that China, India and South Korea are the leading countries. The most scientific productions are presented in the form of conference articles by 49.6 % and magazines by 33.1%, and the fields of computer science and engineering have the highest share in this field with the frequency of 30.4% and 24.6%, respectively. Prieto, J. is also the best author in this field of knowledge.

In [13], studies the impact of IoT technology based scientometrics in countries in East Asia are covered. Based on the method required in scientometrics, the period from 2016 to 2020 was selected based on the Scopus database. The results obtained in this field indicate that China is ahead. In addition, concepts such as smart factories, machine learning and smart cities were prioritized in this research field in terms of frequency. Electronics journal (Switzerland) in this field is leading in terms of the number of published related research topics.

One of the technologies required to improve data exchange in the field of IoT is the use of the semantic web, which has received serious attention today. In this regard, the review and analysis of this field of knowledge based on scientometrics based on the Web of Science database has been investigated and analyzed in the reference. The results of this analysis in the period from 2011 to 2020 indicate that China, America and Spain are the leading countries. Most research productions in this field are related to computer science with 477 research documents, engineering with 325 research documents and telecommunication with 203 research documents. The top author in this field is Blanco-F,Y. with 17 research articles. The two top universities in this field from the point of view of scientific production are University of Vigo and Campus University from Spain [14].

With the introduction of IoT technology in the fourth industrial revolution, the possibility of interaction and knowledge sharing between humans and objects became possible [15]. One of the types of objects in this field is smart appliances that lead to the creation of smart cities. Research based on scientometrics in the field of using IoT and smart cities based on the Web of Science (WoS) database has been conducted from 2011 to 2021 [16].

In this research, few research papers have focused on both IoT and smart cities. Visualization of Similarities viewer (VOSviewer) software is used in the mentioned reference. The trend of published documents shows that the most scientific productions were produced in 2020. In addition, in the mentioned article, the countries and authors who published the most documents were analyzed.

In [17] with using scientometrics analysis, the effects of the emergence of IoT technology in a wide range of objects, processes and environments with living or non-living elements investigated. This study focuses on the scientific map of the IoT based on the Web of Science (WoS) database from 1989 to 2019. In this analysis, 14469 research documents were processed and evaluated using VOSviewer software.

The main focus of this research document is on authors, countries, journals, institutions, etc. The analysis shows that Joel J.P.C Rodrigues was the most prolific author, China was the most prolific

country, IEEE Access was the most influential journal, and Luigi Atzori was the most cited author. The main keywords that were more frequent in the documents were IoT, internet and security, respectively. In another study, using scientometrics, the evolution of blockchain technology is investigated for decision-making processes in the fields related to the IoT and ML.

As presented in [18], blockchain technology can store data and prevent them from being hacked or edited. In this research, the SCOPUS database is used from 2015 to 2023, and 1332 articles is retrieved in the field of digital currency based on blockchain-enabled IoT. The analyses presented in this research show that America is the leading country in this field, wherein the scientific productions are pulished in 2018. Based on this paper, IEEE Access has the most scientific productions in this research field.

Another study in the field of scientometrics refers to the concept of resource management in IoT networks, as described in [19]. In this research, a comprehensive review of research documents between 2012 and 2022 has been conducted using the SCOPUS database to determine the current status of the mentioned field and examine the challenges and opportunities of research in this field. The results of these surveys showed that limited resources will make it challenging to create networks based on the IoT. The results of the analysis show conventional methods such as AI, optimization methods, and game theory approaches are widely used in this field. Of course, in this research, one of the standard methods of AI called DL is also investigated, which will be one of the solutions for allocating resources with low complexity in real time.

In [20], the importance of IoT technology in an Arab countries such as Algeria, Bahrain, Comoro and so on were investigated. For this purpose, the Scopus database was used between 2010 and 2017. The most scientific productions in this field related to 2017 are 607 research documents and the highest amount of referencing is 2002 in 2017. Leading countries in this field are Saudi Arabia, the United Arab Emirates and Tunisia. The top two authors in this field in the names of Jararweh, y. and Al-Ayyoub, M. are from the Jordan University of Science and Technology. Two IEEE Access and Computer Networks journals are the leading journals in the scientific productions of this field. Three fields of computer science, engineering and mathematics are leading in this field.

In [21], the application of IoT technology to the executive management based on scientometrics is investigated using two databases including SCOPUS and WOS from 2010 to 2022. As a result of this research, 1623 published research documents were examined. The study results in the synonym network show frequent topics such as digitization, digital operation, monitoring systems, tracking and intelligence. The leading countries in this field were China, America, and India. The leading journal in this field is IEEE Access. The most cited article domain has 1041 references. Nowadays, the creation of a smart city has been seriously deployed by developed and developing countries. One type of technology that can be used in modern smart cities is the IoT.

In this regard, in the reference research [22], which is based on scientometrics, research documents were reviewed from 2012 to 2021 based on WoS, SCOPUS, and IEEE Xplore databases, and approximately 1019 documents were found. The research results show five frequently used words including IoT, IoT architecture, energy, security and privacy. In addition, the leading countries in this field include India, America, and China. The leading research institute in this field is the National Institute of Technology Nit System. The IEEE IoT journal published most of the documents in this field. Zaslavsky is the best author in this field who has published the most research documents. The article "Internet of Things for Smart Cities" published in the IEEE Internet of Things journal has the most references in the three WoS databases with 2170 references, SCOPUS with 2940 references, and IEEE Xplore with 2694 references.

In [23], wireless transmission methods in the IoT based on scientometrics are investigated. This statistical analysis method was performed based on the WoS database. The results of this evaluation were based on 15102 authors from 3843 organizations in 87 countries, including China, the United States, South Korea, and India, and 6105 articles in 551 publications. The analysis results show that in terms of quantity, China is the most powerful country in the world, which published 1912 articles and accounted for approximately 31.3% of the total number of articles published in this field. In addition, seven Chinese organizations are among the top 10 organizations, and some Chinese researchers have

published articles with high citation frequency in the fields of machinery, computer science, and telecommunications. IoT technology includes devices with limited resources regarding battery power, processing capacity, memory, bandwidth, etc. One of the processes carried out in low-power and low-loss communication networks based on IoT.

In [24], the protocols used from the aspects of reliability, robustness, energy efficiency, and flexibility in low-power and low-loss communication networks based on scientometrics are investigated. For this purpose, the results of the research from 2010 to 2021 are conducted on the use cases of this field, and intelligent networks, smart cities, and smart homes are the most commonly used ones in this field. Today, the challenges of city creation and migration to cities have drawn attention to the sustainable management of land and water resources for productivity in modern agriculture based on the combination of AI and IoT technologies.

In [25], research based on scientometrics in the field of water and land management with the help of AI and IoT is presented. The results of this analysis are based on 436 research articles between 1991 and 2021. The most frequent words include artificial neural networks (ANN), adaptive neural fuzzy inference systems (ANFIS), support vector regression (SVR), random forest (RF), and multilayer perceptron networks artificial neural network (MLP-ANN). In addition, the countries of China, India, Iran, Australia, and the United States of America were recognized as pioneers in this field. While the countries of Italy, Spain, and Saudi Arabia, considered as emerging countries but with low cooperation links, started their initial activities in this field.

In another research, the importance of using IoT in the field of health based on scientometrics is mentioned [26]. In this research, 778 research articles from the WoS database were reviewed from 1998 to 2016. Based on the results obtained, the growth of scientific production in this field has accelerated since 2010. The most important topic of interest in this field is systems and services design and implementation, and people with scientific affiliations from China, America, and England had the most scientific productions.

In another study, as in [27], the situation of using IoT technology between China and the United States based on scientometrics from 2009 to 2018 has been investigated. The results of the analysis show that although China has more research publications in this field but China should try to develop basic and essential technologies based on property rights for more effective competition.

In another study, the role of IoT technology in the field of wireless sensor networks is investigated. For this purpose, between 2002 and 2016, 19035 published documents in WoS and SCOPUS databases were analyzed. In this regard, a software package based on the Python program named ScientoPy was used to analyze the data extracted from the research documents. The results of the analysis show that the countries of China, America and India had the largest share in the publications of this field with 1561, 4822 and 1089 published documents, respectively, based on the affiliation of the authors declared in the documents. In 2016, an author named Y. Zhang was the leader in this field with more than 35 published documents. Of course, an author named L. Atzori from Italy had the highest number of references (3239 reference), in the publication of his research activity in the computer network magazine in 2010.

The most frequent keywords in the articles in this field in 2016 indicated the abundance of wireless sensor networks, cloud computing, and security. In addition, the three most frequent applications in 2016 included smart city, smart home and intelligent network, respectively. The most frequent communication protocol in this field is for the Radio Frequency Identification (RFID) host layer and the Constrained Application Protocol (CoAP) medium layer in 2016 [28].

The most frequent processing methods in this field are ML, data mining and complex event processing. One of the areas where IoT technology can improve its management and services is food security. For this purpose, in the research conducted in [29], the effect of IoT technology on this area, based on scientometrics was investigated. In this research, which was conducted between 2011 and 2018, three databases including SCOPUS (41 related research documents), Science Direct (1 related research document), and Google Scholar (48 related research documents) were used. The top authors of this field of knowledge are L. Zheng, Y. Zhang, J. Wang and W. Han, respectively.

A significant part of the studies and research conducted in this field by Chinese universities is to monitor food products and product quality. The most widely used communication technologies in this field were RFID and wireless sensor

networks. Nowadays, the use of AI techniques such as ML for global navigation satellite systems (GNSS) based on IoT to monitor and predict the ionosphere layer, which leads to cost reduction-, is receiving serious attention. In [30], a ground navigation system based on machine-to-machine (M2M) communication is proposed, which can provide navigation information and services required by users.

In [31], the authors focused on providing an educational framework based on federated learning (FL) in IoT edge computing, which can be used to manage natural resources such as forest areas. The proposed method can reduce the time required for data processing in the system by increasing privacy.

3. RESEARCH METHODOLOGY

The results presented in this article include a review of documents (including articles published in journals, conference articles, books, reports, etc.) published worldwide in the field of AI in satellite-based IoT using scientometric tools.

For this purpose, it is necessary to extract published documents in this domain and perform relevant analysis. As for the first step, in the SCOPUS citation database, the domain was searched as follows:

(TITLE-ABS-KEY ("Satellite" AND ("internet of thing*" OR "IOT")) AND TITLE-ABS-KEY (("Artificial Intelligence" OR "Neuro scale algorithm" OR "weighted fuzzy scoring" OR "support vector machine" OR "Pattern Recognition" OR "Machine Learning" OR "Machine Vision" OR "Image Processing" OR "Data mining" OR "Fuzzy Reasoning" OR "Deep learning" OR "Fuzzy Inference Systems" OR "Genetic algorithm*" OR "Evolutionary Algorithm*" OR "Random Forest" OR "Decision tree" OR "Neural network*" OR "k-nearest neighbors algorithm*" OR "Federated Learning" OR "Reinforcement Learning" OR "Soft computing" OR "Unsupervised learning" OR "SVM-based spectrum sensing" OR "Markov model" OR "Extreme learning machine" OR "Neural Turing machine" OR "Generative Learning" OR "Deep Convolutional Network" OR "fuzzy logic" OR "fuzzy system*" OR "supervised learning" OR " statistical learning")) AND NOT TITLE-ABS-KEY ("IOT (In-Orbit Test)").

The search strategy was carried out in the title, abstract and keywords of the documents indexed in the Scopus database. The number of results obtained on 2023.12.10 equals 475 documents (including articles, books, etc.). The documents were downloaded in the RIS format.

In the second step, Excel and Bibexcel software were used to create the co-occurrence matrices (for Co-words network and Co-country network). Before creating of co-occurrence matrices, the necessary actions were taken to remove unrelated and meaningless keywords, and the singular and plural words were also standardized. However, according to experts, words that were conceptually synonymous were also merged into one word. The threshold limit considered in Bibexcel software for the frequency of words in the documents was set as 3. Finally, using the VOSviewer software, this area was visualized.

4. RESEARCH FINDINGS

The number of published documents worldwide and the number of citations for published documents versus year in this domain field and its trends are shown in Figure 1 and Figure 2, respectively. As can be seen in the Figure 1, the scientific growth of this domain field from the year 2018 with the total publications of 18 research documents increased significantly compared to the beginning in 2013.

The number of published documents worldwide in 2023 has not been finalized yet. Also, most citation published documents are 2633 for 2023. The status of the types of published documents (conference articles, journal articles, books, book chapters, etc.) in this field is shown in Figure 3.

As it depicts, the total articles published during 2013-2023 with the value of 42% has the highest weight among the published documents, and, book chapters with about 7% has the lowest weight in the total number of publications. The authors, with the highest number of published documents, are also shown in Table 1.

In Table 1, TP is the total papers in the SCOPUS database wherein TC is the total number of citations for each publications and CPP is the total number of received citations count divided by the total number of publications in the SCOPUS database. In addition, the top journals of the world, which have the most scientific productions in this field, are listed in Table 2.

The frequency of the type of AI mechanism used is presented in Table 3. The ranking status of the countries with the most degrees published is also shown in Figure 4. As it is observed, the countries of China, India and America are at the top of this ranking. The status and the total number of published documents in different subject areas are shown in Fig. 5.

As it is apparent in the above figure, the fields of "Computer Science" and "Engineering" have the highest number of documents in this field. The collaboration network of the top authors in this field is shown in Fig. 6.

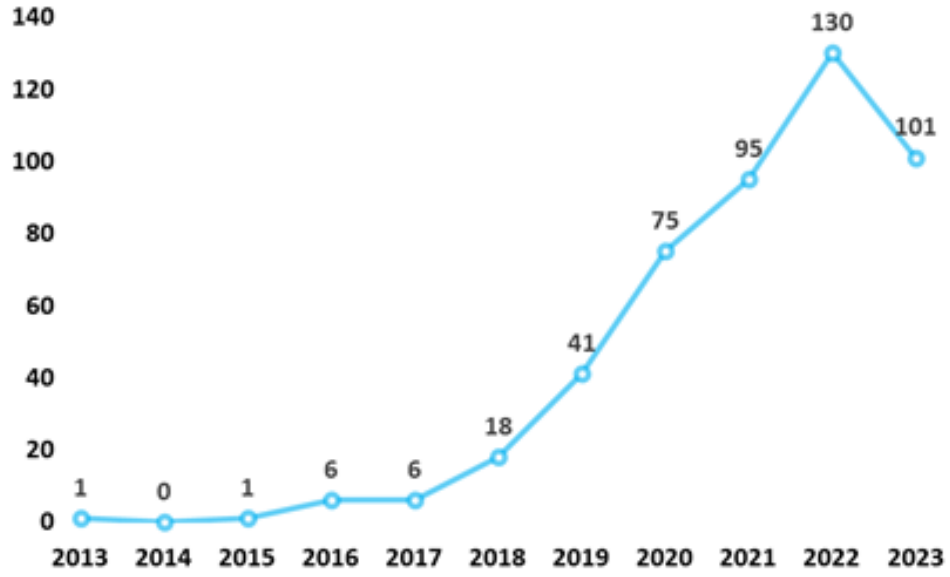

Fig. 1. Number of published documents in the field of "utilizing AI in satellite-based IoT".

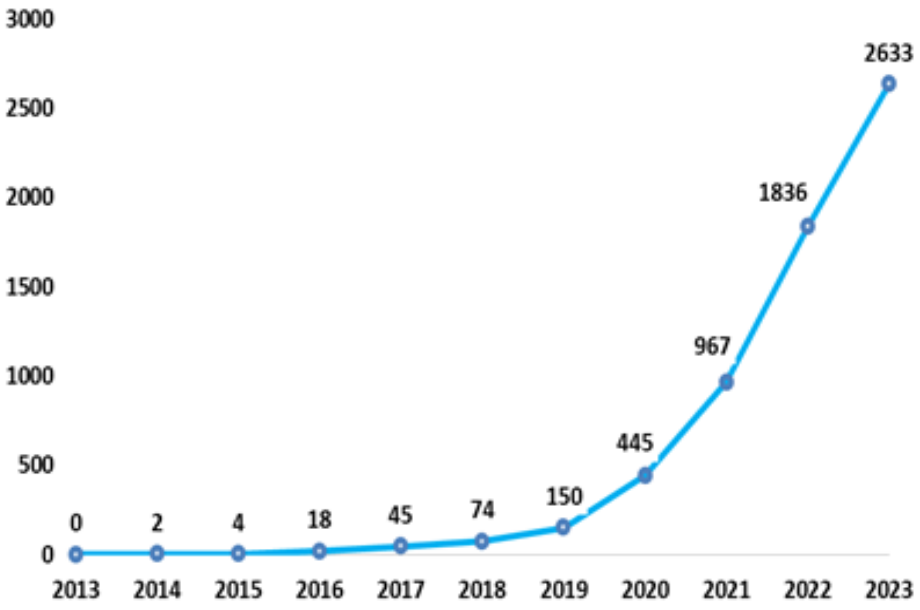

Fig. 2. Number of citations for published documents in "utilizing AI in satellite-based IoT".

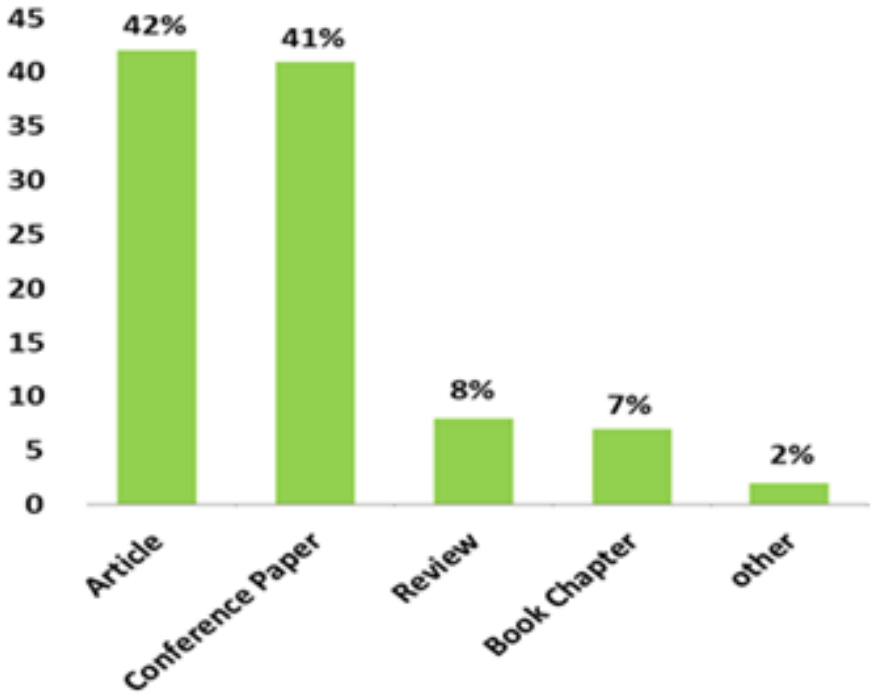

Fig. 3. The types of published documents in "utilizing AI in satellite-based IoT".

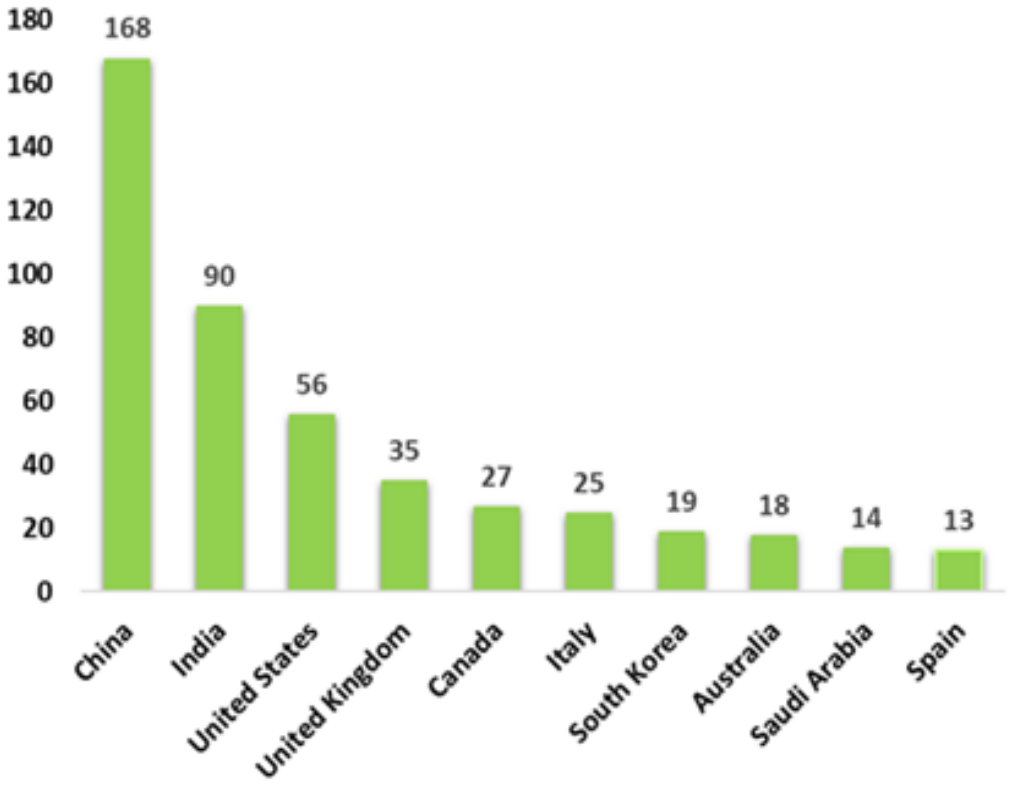

Fig. 4. Leading countries in the field of "utilizing AI in satellite-based IoT".

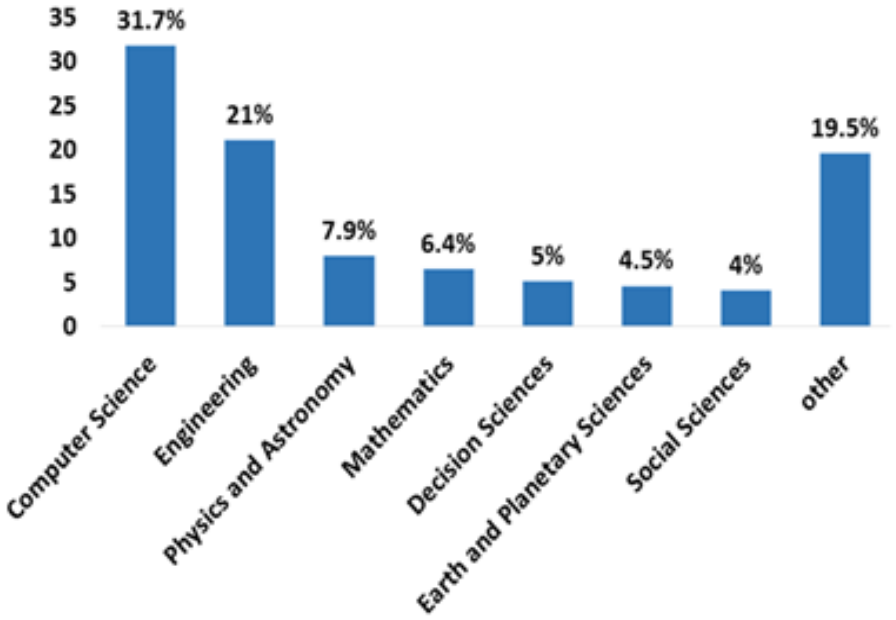

Fig. 5. The percentage of published documents in different subject areas in "utilizing AI in satellite-based IoT".

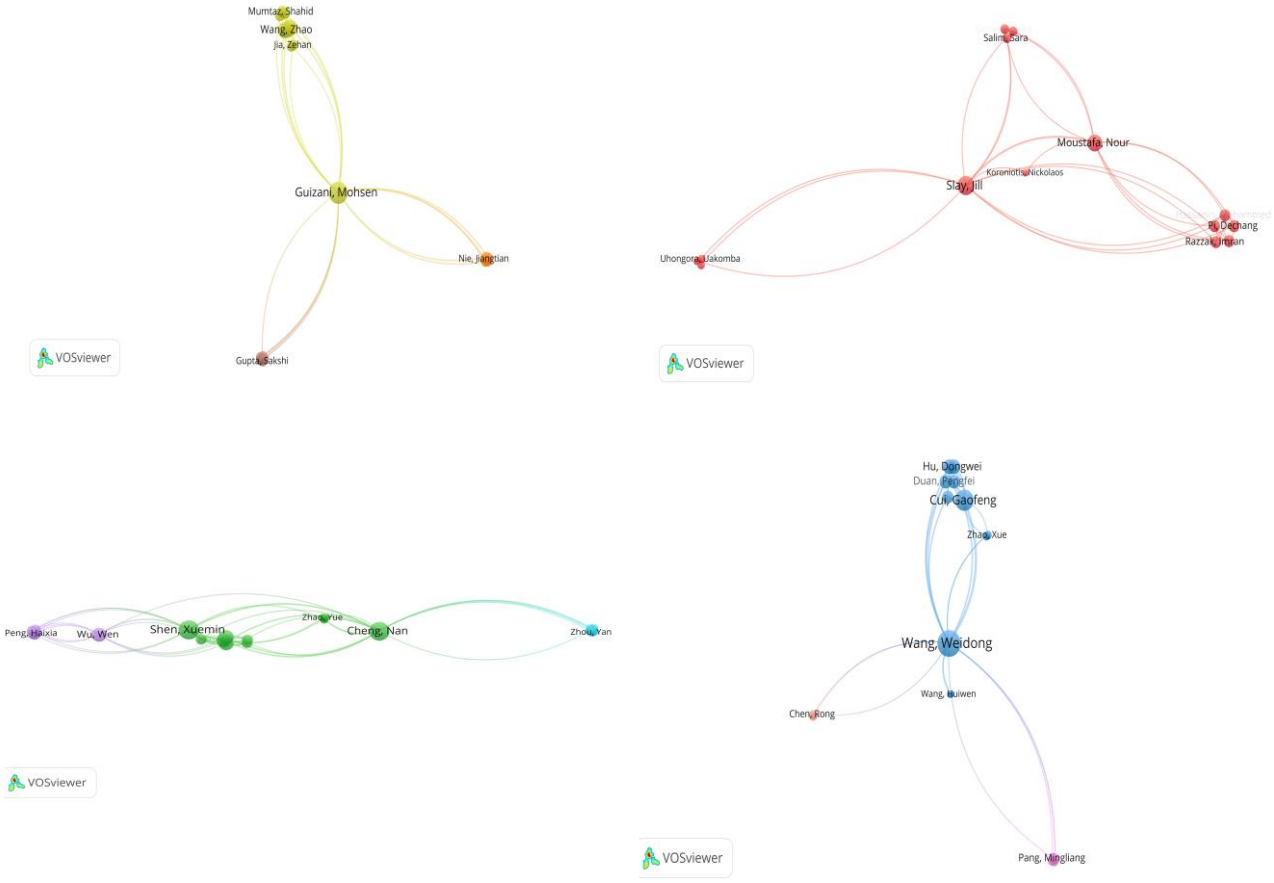

Fig. 6. Co-authorship network based on table 1 in the field of "utilizing AI in satellite-based IoT".

Table 1. Top authors in "utilizing AI in satellite-based IoT".

Author name	TP	TC	CPP
Wang, W.	8	121	15.13
Cui, G.	5	98	19.6
Shen, X.	4	654	163.5
Cheng, N.	4	654	163.5
Guizani, M.	4	139	34.75
Slay, J.	4	11	2.75

Table 2. Top journals on "utilizing AI in satellite-based IoT".

Source Title	Count
IEEE Internet of Things Journal	27
IEEE Access	12
MDPI Sensors	11
MDPI Electronics	7
Proceedings of The International Astronautical Congress	7
ACM International Conference Proceeding Series	7

Table 3. Frequency of "AI algorithms in satellite-based IoT".

Keyword	The frequency of use
Machine Learning (ML)	115
Deep Learning (DL)	99
Reinforcement Learning (RL)	45
Neural Networks (NN)	25
Convolutional Neural Network (CNN)	18

Consequently, to outline the knowledge structure of this research domain, by using the outputs from the "SCOPUS" database and the Bibexcel software, the analysis of the relevant words throughout the documents was initially performed. In this section, the words in the extracted documents and the most relevant words have been selected to present on the network.

This process causes the words that are less important to be removed and lets the network focus only on the major words. In the next step, the output obtained from the Bibexcel software is fed to the VOSviewer software. The results based on this process is given in Fig. 7.

The size of the circles in Figure 8 indicates the total count of the word. As it is evident in this figure, the words "IoT", "ML", "Satellites", "DL", and "AI" with 326, 115, 112, 99 and 96 usage frequencies, have the highest count in the total published documents. In this map, each of the used colors represents a topic cluster. As it is observed, the target words are classified into seven clusters.

The density network is shown in Figure 8. In this figure, the highest density of words in the network is shown in red. In the same way, yellow, green and blue ones have the highest density. The distance of the words also has meanings. For example, if the distance between two words is relatively small, it can be inferred that they are used mainly together in many documents. Also, if the distance between two words is considerable, these two words are used together in few documents.

Moreover, the state of communication and international scientific cooperation between the countries is shown in Figure 9. As shown in this figure, 64 countries have international scientific cooperation in this field, among which China, United Kingdom and America have the highest cooperation. Examining the co-occurrence map of the vocabulary of this field shows that there are seven major topic clusters. Cluster one has sixty-five words including AI, big data and information management. In the second cluster with sixty-three words, there are terms like IoT, ML and remote sensing.

The third cluster with fifty-one words includes satellites, orbits and satellite communication systems. In the fourth cluster, there are fifty words including global positioning system, global satellite navigation system. The fifth cluster includes things like DL, antennas and RL with forty-four words. The sixth cluster with thirty words includes things like learning systems, network security and forecasting.

Finally, the seventh cluster with twenty-three words contains data communication system, spatial lights and car-to-car communication. In Table 4, according to the output of the VOSviewer software, a total of 7 subject clusters have been extracted. In this table, one column refers to the main topic of each cluster and other research priority topics in the subset of this cluster.

5. CONCLUSIONS

There are various methods to study, analyze and classify the specifications and characteristics of a research field. In this article, we performed this using scientometric analysis in the investigation of "Using AI in satellite-based IoT".

In addition, the relationship between its thematic sub-areas and international cooperation was deduced. The review of retrieved publications in this field until 2023 showed 475 documents indexed in the SCOPUS database.

The major growth in the total number of publications in this field in recent years, shows the importance and practicality of this field technology. According to the results deduced from this study, China, India and North America are the leading countries in the research of this domain filed at the global level. Also, based on our findings, the terms including machine learning, deep learning, reinforcement learning, neural networks and convolutional neural networks have been used the most in this domain. Wang, W. has the most number of articles in the obtained results with eight published papers. With 27 published articles, IEEE Internet of Things Journal is the most chosen magazine in this research field. Computer science has the most research activity in this field with a share of 31.7%.

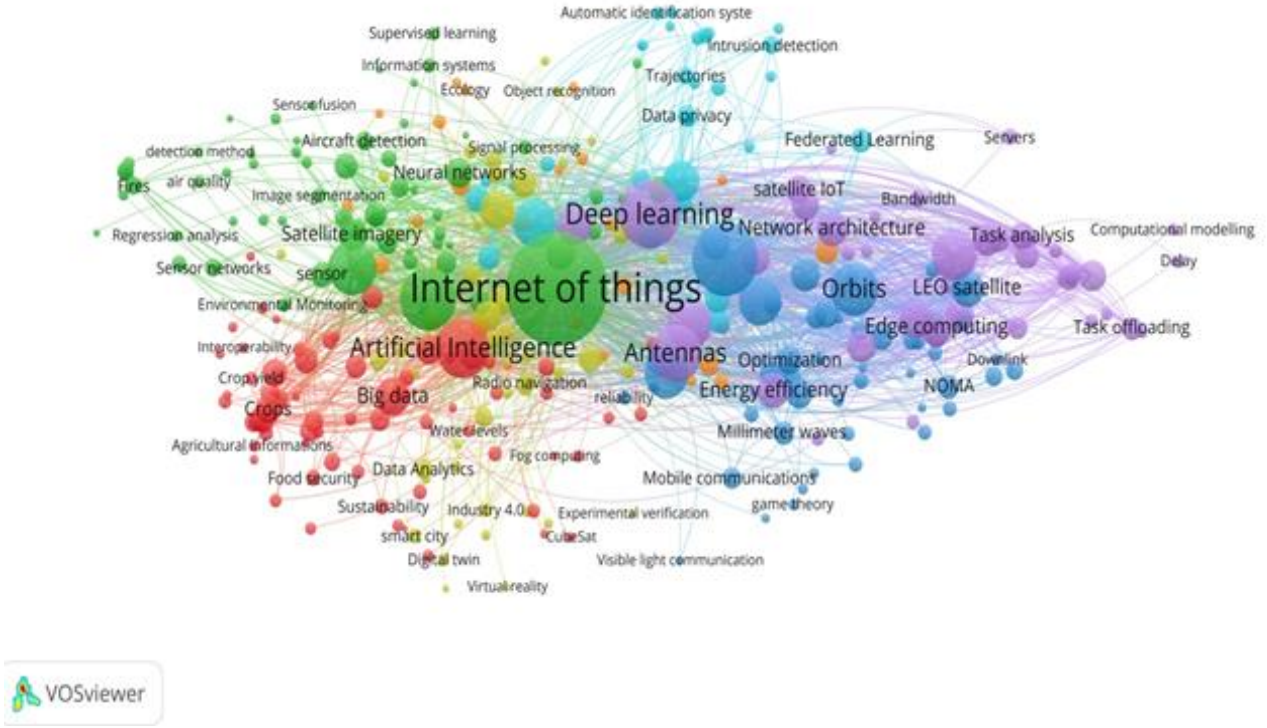

Fig. 7. Co-words network in the field of "utilizing AI in satellite-based IoT".

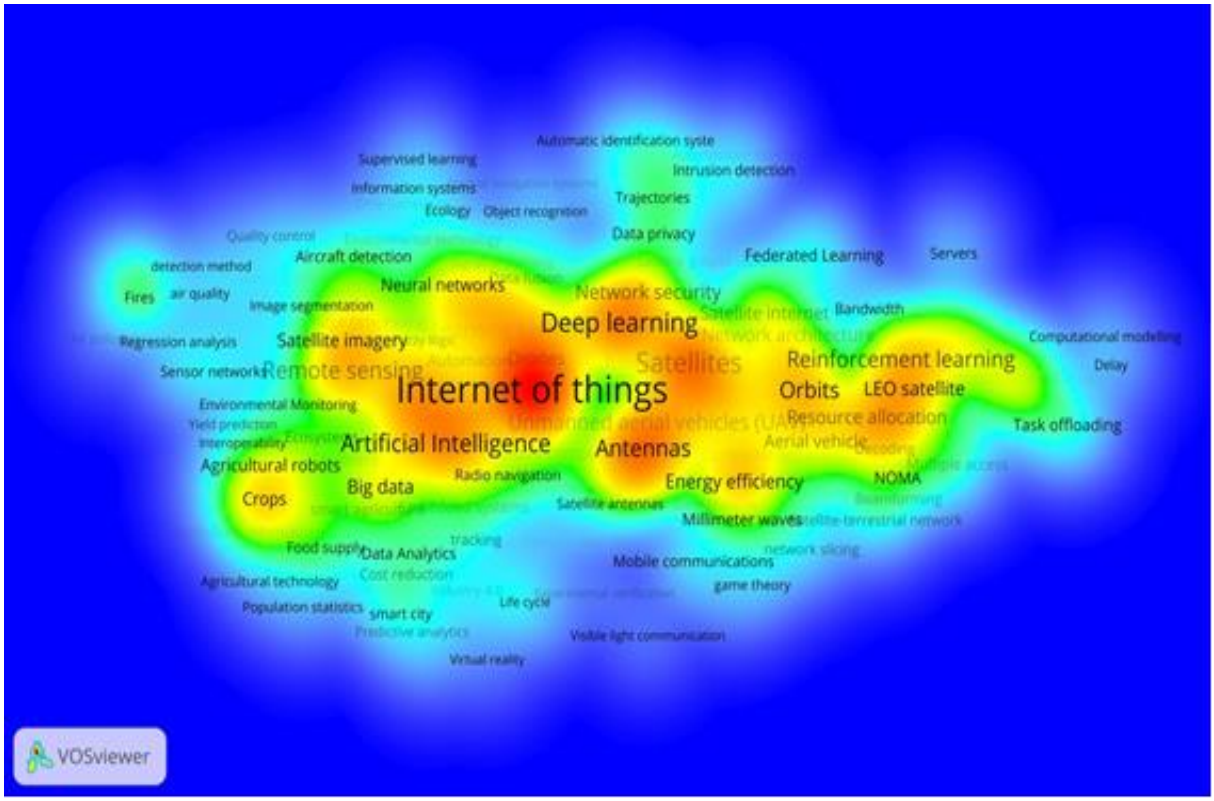

Fig. 8. Density network in the field of "utilizing AI in satellite-based IoT".

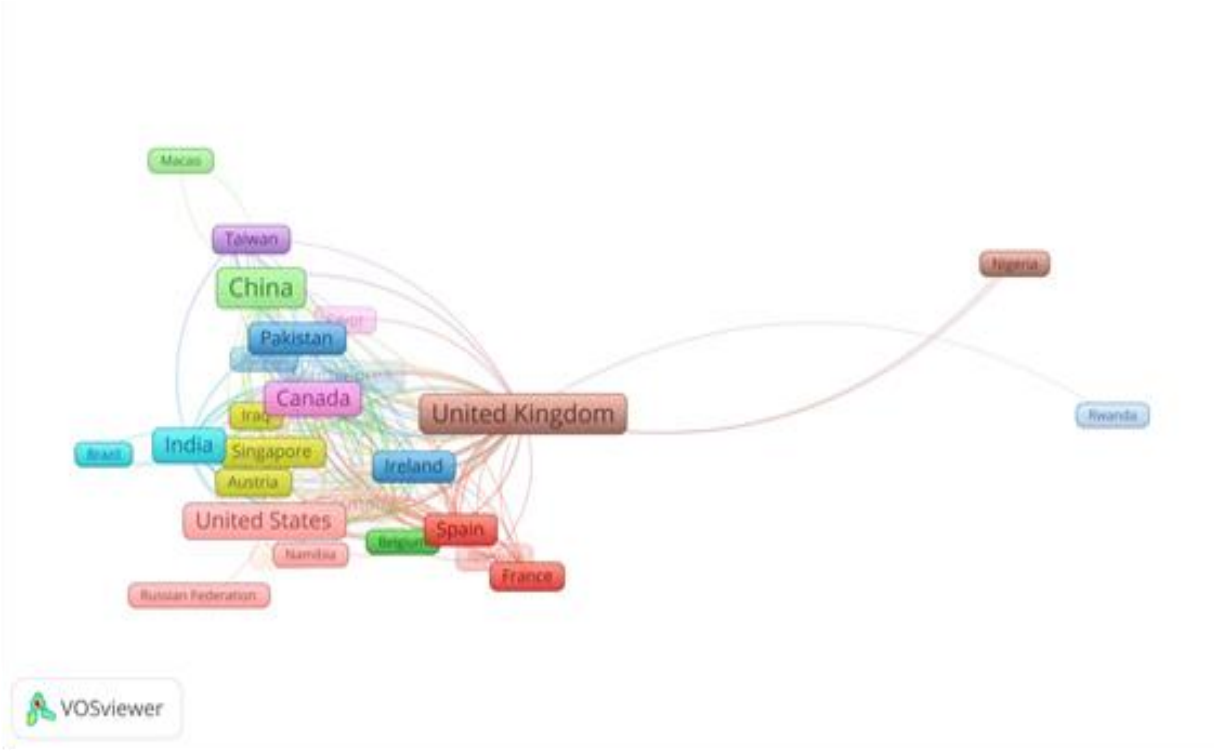

Fig. 9. International scientific cooperation among countries in "utilizing AI in satellite-based IoT".

Table 4. Classification of existing clusters in the field of "utilizing AI in satellite-based IoT" until 2023 (according to Fig.7).

number of clusters	Major issues for each cluster	Some major related topics clusters by frequency
1	Intelligence management	Artificial Intelligence, Big Data and Information Management
2	Intelligence monitoring	Remote sensing, Satellite Imagery and Satellite Remote Sensing
3	Satellite communication	Satellites, Orbits and LEO Satellite
4	Navigation systems	Global Navigation Satellite Systems and Radio Navigation
5	Resource management	Resource Allocation, Energy Efficiency and Convex Optimization
6	Security	Network Security, Cybersecurity and Data Privacy
7	Communication systems	Vehicle to Vehicle Communications, Cellular Network and Space Platforms

CONFLICT OF INTERESTS

No conflict of interest has been expressed by the authors.

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