Advancing Healthcare: A Comprehensive Review and Future Outlook of IoT Innovations

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ABSTRACT

Rapid innovation leading to better patient outcomes have been driven by recent breakthroughs in the Internet of Things (IoT), which have drastically changed the healthcare sector. In order to highlight the importance of IoT in healthcare applications, this article presents a user-friendly and integrated approach for bibliometric analysis. Traditional bibliometric methods often rely solely on Web of Science (WoS) or Scopus, limiting the scope of analysis. To address this issue, the proposed approach uses the R program Bibliometrix to combine data from seven databases, namely Scopus, WoS, IEEE, ACM Digital Library, PubMed, Science Direct, and Google Scholar (GS). After having developed an inclusion/exclusion criterion, 2,990 journal papers published between 2011 and 2022 were subjected to a thorough literature review and

bibliometric analysis. This study demonstrates that the healthcare industry is highly interested in the IoT, as well as the rapid growth of research into IoT healthcare applications, blockchain, Artificial Intelligence (AI), 5G telecoms, and data analytics. Authentication methods, fog computing, cloud-IoT integration, cognitive smart healthcare, and other essential topics are further examined by employing co-citation network analysis. In addition to illuminating potential avenues for further investigation, these results provide academics with a comprehensive picture of where IoT research in healthcare is standing at the moment. The output of the conducted analysis shows that there has been a dramatic uptick in publishing since 2017, with most of the articles appearing in prestigious journals related to computer science. By integrating data from multiple databases, the proposed methodology represents a significant advancement in bibliometric analysis, enabling a more comprehensive exploration of IoT's impact on healthcare, and facilitating a deeper understanding of the emerging trends and critical themes in this rapidly evolving field.

Keywords-IoT; advanced healthcare; bibliometric analysis; blockchain; artificial intelligence

I. INTRODUCTION

Aging population, changing disease patterns, the larger percentage of women in the workforce, and the rising healthcare costs are some of the major factors driving the growth of home healthcare services in Europe [1]. However, these tendencies are not specifically observed there. They are globally witnessed, instead, driving up a demand for home healthcare. The latter fills in the gaps in the healthcare system by offering primary, secondary, and tertiary care prior to and following hospitalization. The COVID-19 pandemic has brought attention to the significance of home healthcare, as patients' behavior towards the use of healthcare services has been greatly impacted by their increased fears about the spread of the specific disease [2]. As a result, "HomeHealth" and "Telemedicine" services have become increasingly popular, indicating a general trend toward home-based care options [3, 4].

A. Healthcare and the Significance of IoT

Similarly to other fields [7] technology can improve healthcare accessibility and reduce costs by providing affordable medical solutions even though it cannot stop the population's inexorable aging or instantly eradicate chronic diseases. IoT is a cutting-edge concept with many uses, particularly in the medical field. Both patients and healthcare providers can benefit from the complete implementation of IoT in healthcare services: patients receive higher-quality care, and healthcare providers can increase their operational efficiency. This novel strategy promises to significantly enhance patient outcomes in terms of health and quality of life, especially for older patients, by significantly increasing the effectiveness and caliber of medical treatments.

B. Potential Benefits and Difficulties

The integration of IoT in healthcare, though relatively new, has already demonstrated significant advantages. One of the most crucial benefits of IoT devices in this sector is their ability to monitor and report patient health conditions in real-time. These Internet of Medical Things (IoMT) devices facilitate comprehensive patient data collection and analysis, enabling continuous health tracking and generating alerts for any anomalies. Beyond remote health monitoring, IoMT devices also support the provision of remote medical assistance, fostering seamless connectivity between patients and their healthcare providers. This connectivity not only reduces the cost of health monitoring and minimizes the need for physical visits by medical professionals, but also advances research in patient health, monitoring, and telemedicine. In essence, IoMT is revolutionizing healthcare by enhancing efficiency, accessibility, and patient outcomes.

Implementing IoT systems in healthcare presents significant challenges despite its potential benefits. Foremost among these challenges is the critical issue of data security and privacy [8-13]. The integration of diverse devices and protocols introduces complexities that can hinder seamless implementation [14]. Over time, these systems may face challenges, such as data overload and maintaining accuracy, further complicating their effective operation in clinical settings. Moreover, the initial and ongoing costs associated with purchasing or leasing IoT devices pose financial challenges to healthcare providers, potentially limiting the widespread adoption and scalability of these technologies. Addressing these multifaceted problems is crucial for harnessing the full potential of IoT to revolutionize healthcare delivery while ensuring patient safety and data integrity.

C. Related Works

Recent bibliometric analyses have shed light on the evolving landscape of home health and IoMT. One study, drawing from a comprehensive dataset of 1000 documents sourced from Scopus, explored the intersection of home health with IoMT, revealing a prospective emphasis on integrating assisted living solutions for elderly patients with health monitoring devices [15]. This suggests a future trend toward enhancing elderly care through technological interventions. Similarly, another analysis leveraging 778 articles from the WoS over an eighteen-year span identified eight distinct trends in IoMT, illustrating the diverse applications and advancements in healthcare technology through text mining and abstract analysis [16]. These studies collectively underscore the growing significance IoMT in shaping the future of healthcare delivery and monitoring.

By sifting through 2,339 articles published in the smart home IoT sector between 2015 and 2019 and stored in the SCOPUS database, a thorough bibliometric analysis was performed in [17]. Moreover, bibliometric methods were used to determine trends, publication patterns, important documents, publication areas, and noteworthy subjects in the field of IoT research from 1970 to 2019 [18]. Nevertheless, the Scopus database was the exclusive focus of both investigations. In contrast, 89 papers out of 3,678 were ultimately selected based on strict inclusion/exclusion criteria in a systematic mapping study that examined the role of IoT in medicine. The study evaluated researches issued between 2000 and 2018 across major scientific databases, such as Scopus, WoS, IEEE Xplore, and PubMed [19]. Data from Scopus, which was selected owing to its compatibility with the Bibliometrix R package, were also used in a bibliometric study of worldwide research publications pertaining to digital and mobile health. The study showed that the number of studies on these topics increased gradually up until 2016, and then there was a sudden surge in 2017 [20].

To conduct bibliometric analysis, a variety of tools are deployed, including data collection, evaluation, science mapping, and visualization. The Bibliometrix R program and its user-friendly web-based platform, Biblioshiny, stand out because of their vast features and widespread use [21]. In [22], Bibliometrix, VOSviewer, and Microsoft Excel were utilized to examine publications on the Omicron version of COVID-19 from 2020 to 2022. An analysis of 778 papers pertaining to the IoMT was conducted employing BibExcel, which was retrieved from WoS [16]. In [23], VOSviewer examined the current status, trends, and gaps in hospital waste management research, highlighting possible topics that should be further investigated. The Publish or Perish software, which retrieves data from GS, has been used to study digital learning articles related to COVID-19 [24] and IoT applications in irrigation using Scopus data [25]. Publish or Perish, along with VOSviewer, was also instrumental in examining Industry 4.0 literature [26] and Society 5.0 research [27], analyzing publication features, subjects, geographical distribution, and keywords. Table I displays a selection of review articles about the healthcare-related IoT research.

TABLE I. ARTICLES REVIEWING THE LITERATURE ON HEALTHCARE BASED ON THE INTERNET OF THINGS

Ref.	Approach	No. of articles	Time span	Focus
[28]	Traditional literature review	-		In order to investigate how innovative technologies, like blockchain and the IoT, may enhance healthcare provision.
[29]	Traditional literature review	-		For the purpose of showcasing the IoT architecture, applications, technology, and security advancements made in relation to the IoT in the fight against the HIV/AIDS epidemic.
[30]	Traditional literature review	-		In order to give a comprehensive analysis of healthcare IoT systems that rely on mobile edge computing (MEC).
[31]	Systematic literature review	60	2000–2016	In order to determine the primary IoT healthcare applications, characteristics of the IoT cloud-based architecture, issues with interoperability and security, and obstacles to the widespread use of IoT in healthcare.
[32]	Systematic literature review	62	2000-2016	Presenting current developments in IoT-based solutions that enable vital nursing tasks in healthcare settings, this presentation aims to acquaint the nursing audience with the concept of IoT.
[33]	Systematic literature review	116	2011-2019	Research into the healthcare sector's impacts, mobile computing's function in allowing IoT applications, and confidentiality and safety concerns related to IoT devices is necessary.
[34]	Systematic literature review	146	2015-2020	Current research on healthcare IoT has to be organized in a systematic way. The objective of this literature review is to classify healthcare IoT studies into various groups based on the research methodologies employed, such as security-based, application-based, communication-based, resource-based, and sensor-based approaches.
[35]	Systematic literature review	105	2005-2021	This literature review analyzes IoT in healthcare research, organizes publications according to trends, showcases use cases, expands current classifications, and considers IoT models, success variables, and deployment challenges.
[36]	Systematic literature review	46	-	This literature review determines the effects of the Internet of Things Big Data Analytics (IoTBDA) paradigm on healthcare service providers' capacity to develop, test, and execute IoT-based solutions by mapping the existing study environment surrounding this approach.

D. Research Motivation

An essential technique for assessing the quality of research partnerships between academic institutions is the bibliometric studies. A static, organized, and easily observable depiction of research activity is provided by this methodology [36]. In order to find both quantitative and qualitative changes within a certain research topic, bibliometric analysis deploys statistical methods, which is a well-established meta-analysis technique [39]. Its many applications span several domains, from sustainability and healthcare to blockchain technology and IoT [38-40]. Being a thorough method for comprehending and analyzing scientific data, bibliometric analysis examines large numbers of publications. This method not only sheds light on the processes of evolution in certain domains, but it also identifies and prioritizes new areas of research, providing useful information on how these subjects are progressing.

The majority of articles used in modern bibliometric research come from databases like Scopus or WoS. A small number of researchers merge these databases for a single study, but they seldom detail the procedures they used. A bibliometric study of sales force literature was utilized to assess a recently proposed method for merging the Scopus and WoS databases deploying a four-step process. Just papers and conference proceedings were considered in this analysis upon which an approach to merging Scopus and WoS data that is both easy to use and is based on the previously discussed strategy has been proposed [41]. This approach, detailed in a later study, streamlines important steps of combining datasets with the help of the R tool Bibliometrix. To ensure the data integrity of bibliometric studies, it offers a three-step, easy-to-use approach that does not require coding expertise or specialized software. Nevertheless, this approach can be only employed to merge these two databases.

Consequently, a unified approach is urgently required to compile bibliometric data from all main sources. A research on the IoMT is the focus of the current paper, which presents a novel method for bibliometric analysis. As far as is known, this is the first comprehensive methodology to date to provide bibliometric analysis across several databases. Researchers, particularly those just starting out in a subject, will find the proposed strategy useful for sifting through citation counts, prolific writers, and new research trends to discover the most influential articles. The purpose of this tool is to assess the present status of a topic by taking into account indicators, such as the number of citations, top researchers, journals, universities, and nations that have made significant contributions. Without the need for coding abilities or specific tools, the proposed methodology enables integrative bibliometric analysis in every field of study.

E. Research Objectives

With an emphasis on the developing subject of the IoMT, the present work attempts to close a major discrepancy in the present bibliometric investigations. Unlike current polls and mappings covering more general areas of IoT research, this work suggests an integrated approach for bibliometric analysis, integrating data from many research databases outside conventional resources, like WoS and Scopus. Using suitable technologies, the approach consists of thorough procedures for data collecting, cleansing, and integration. This method helps assess and expose important research themes in the IoMT and their application in medical environments. It also seeks to name eminent academics, their affiliations, chosen keywords, and the links among scholarly publications. Eventually, the present study aims to draw attention to important areas of focus in the future IoMT domain research.

II. METHODOLOGY

The proposed methodology involves three key steps: data collection, integration, and cleaning. Data will be gathered from relevant sources, integrated into a unified framework, and meticulously cleaned to ensure accuracy and consistency. This approach aims to establish a reliable basis for deriving insights and drawing conclusions from the collected data.

A. Data Collection

Scopus, WoS, IEEE Xplore, ACM Digital Library, PubMed, Science Direct, and GS were among the renowned databases that were employed for data collection. Database-specific search terms were utilized to glean the pertinent articles. The search results can be downloaded in a variety of forms, including CSV, Excel, and Latex, from Scopus, PubMed, and WoS. These files were then saved as .bib files. The current study was able to carry out more precise searches by using the sophisticated search capabilities of GS, IEEE Xplore, and Science Direct. Having been allowed to specify a range of publication dates, authors, and sources, among other advanced search options, this study managed to refine the conducted search and get more relevant results. In [42], certain comprehensive guidelines on how to use IEEE Xplore and Science Direct for advanced search purposes can be found. All the necessary and pertinent data for the performed investigation were collected by employing these strategies. The present study meticulously customized the search strings for each database to guarantee accurate and pertinent results. These strings focused on the article title, abstract, and keywords, with the exception of GS, where the constraints on abstract and keyword searches meant that only the document title was taken into account. Given that the ACM Digital Library only allows 50 papers to be displayed at once, all of the material had to be exported in .bib format and be then combined into one file. On the other hand, Publish or Perish is necessary to retrieve results because GS does not have a bulk export function [43]. However, in order to obtain all the important data, the search term has to be split into substrings because this software only returns 1000 results per search. The outcomes of Publish or Perish and GS had to be consistent with each other. Table II depicts the exact query strings used for all databases.

The citation information necessary to perform citation, co-citation, and analysis of the most popular authors may not be included in the results returned by Publish or Perish. The latter allows an individual to search for citations, examine and change the properties of the chosen data, and more. The results for a search for citing references are displayed in the GS referencing window. Citation information can be obtained when one or more results are chosen from another search. The citation information for both GS substrings was retrieved using the Publish or Perish tool. Afterward, the information was saved in an Excel file along with headers. To make these data compatible with data from other databases, formatting is required before they can be used in Biblioshiny. The tag names should be changed to comply with Biblioshiny standards, and ',' separating keywords should be replaced with ';'. For smooth integration, it has to be ascertained that the data are formatted identically the way R exports them.

B. Data Integration

Due to the different results each database produces, researchers used to independently employ WoS or Scopus in prior bibliometric investigations. On the other hand, the current research takes a holistic view by combining data from different search engines. Excel and the R package are both capable of carrying out the data integration procedure. Excel was selected due to its remarkable capability to save rare tags, which are essential for bibliometric research. The R package provides a quick and straightforward method to combine data using common tags, but it ignores unusual columns. Seven databases' worth of data were integrated for this investigation using Biblioshiny and Excel. Biblioshiny is web software that integrates Bibliometric with the Shiny package, which provides a user-friendly online interface [44]. The Bibliometric package can be now utilized by people who are not programmers. After each database's data were entered into Biblioshiny, they were exported to Excel separately. Table II lays out the sources, search strategy, and data format.

C. Data Cleaning

Data cleansing is an essential step to eliminate duplicate and unnecessary content. During this study's data integration process, all raw data were combined without initially considering duplicates, using title, year, and author as criteria. Although a single line of R code can eliminate duplicates, it risks losing valuable, rare columns.

TABLE II. DATA FORMATS USED BY EACH DATABASE, SEARCH TERMS USED, DATABASES SEARCHED, AND THE OBTAINED RESULTS

Database	Search strategy	Data format
Scopus	"Internet of medical things" OR "IoMT" OR " Internet of Health Things" OR "IoHT" OR "Internet of Things for Medical Devices" OR "IoT Medical Devices" OR "Smart Health" OR" Wearable Devices" AND "healthcare" AND" Medical."	.bib
GS	1. healthcare "internet of medical things" OR IoMT OR" Internet of Health Things" OR IoHT OR" Internet of Things for Medical Devices" OR "IoT Medical Devices" OR "Smart Health" OR "Wearable Devices." 2. medical "internet of medical things" OR IoMT OR" Internet of Health Things" OR IoHT OR" Internet of Things for Medical Devices" OR"IoT Medical Devices" OR "Smart Health" OR" Wearable Devices.	Exported to Excel from Perish or Publish software
WoS	"Internet of medical things" OR IoMT OR "Internet of Health Things" OR IoHT OR "Internet of Things for Medical Devices" OR "IoT Medical Devices".	.bib
IEEE Explore	"Internet of medical things" OR "IoMT" OR "Internet of Things for Medical Devices" OR "IoT Medical Devices" OR "Internet of Health Things" OR "IoHT."	.bib
ACM	"Internet of medical things" OR "IoMT" OR "Internet of Health Things" OR "IoHT" OR "Internet of Things for Medical Devices" OR "IoT Medical Devices" OR "Smart Health" OR" Wearable Devices" AND "healthcare" AND" Medical."	.bib
Science Direct	"Internet of medical things" OR "IoMT" OR "Internet of Things for Medical Devices" OR "IoT Medical Devices" OR "Internet of Health Things" OR "IoHT."	.bib
PubMed	"Internet of medical things" OR "IoMT" OR "Internet of Things for Medical Devices" OR "IoT Medical Devices" OR "Internet of Health Things" OR "IoHT."	.txt

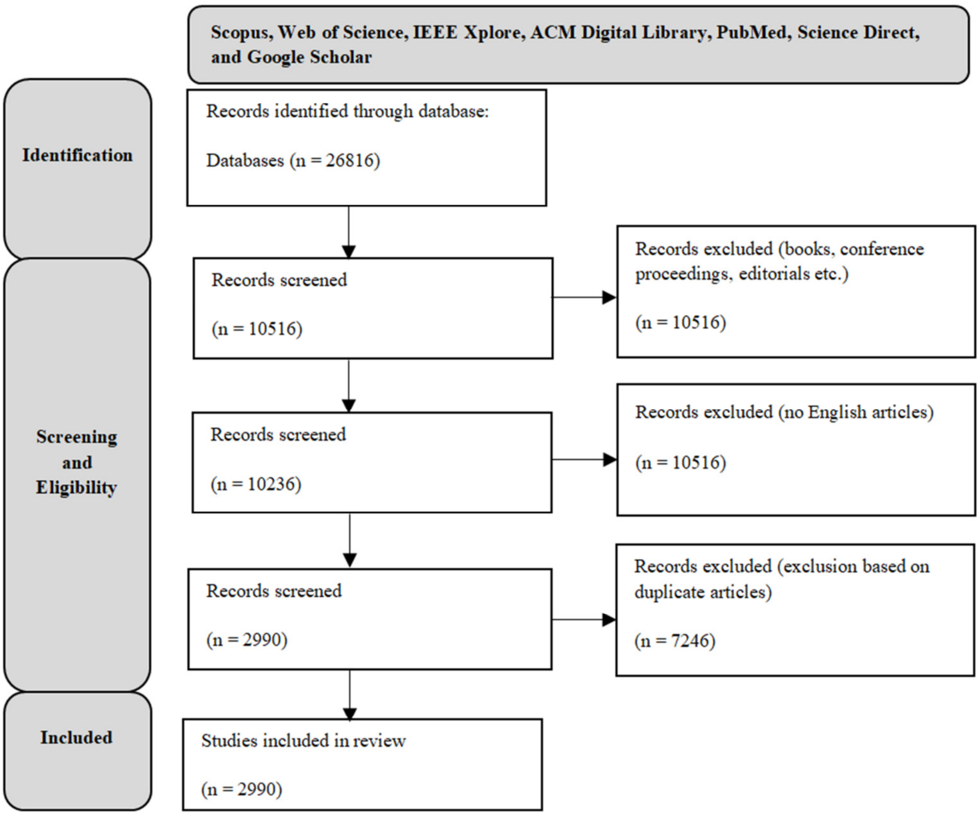

Fig. 1. Methodology of the current study.

Therefore, the data were cleaned in Excel, yielding 26,816 documents as of 2022. To ensure maximum coverage of relevant publications, no subject areas were pre-selected and only English-language journal articles and reviews were included, excluding books, chapters, conference proceedings, notes, editorials, and reports. This resulted in the elimination of 16,300 documents, retaining 10,516 publications. Further refining for scholarly quality and comparability led to 10,236 articles for analysis. Due to the large dataset, three authors manually screened the remaining publications by reviewing titles, abstracts, and full texts when necessary. Discrepancies were resolved by consensus. Articles unrelated to IoT applications in healthcare, such as those focused on soil, plant, and animal health, were excluded, ultimately identifying 2,990 relevant articles for the review. The search and selection process is depicted in Figure 1.

III. RESULTS AND DISCUSSION

A. Statistical Descriptions

Since 2011, there has been a significant upward trend in IoT-related research within the healthcare sector, reflected in the analysis of 2990 relevant publications in this study's sample pool. This trend was particularly pronounced from 2018 to 2022, indicating growing interest and advancements in this field over the years, as illustrated in Figure 2. The earliest studies, dating back to 2011, focused on pioneering applications of the IoT in healthcare, laying the groundwork for subsequent research endeavors.

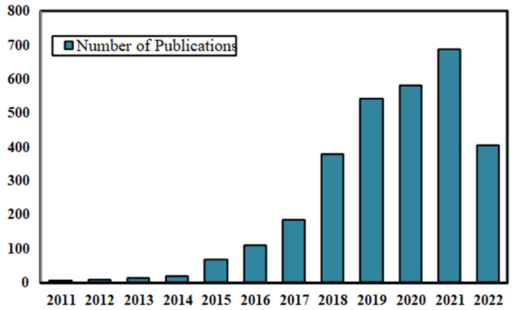

Fig. 2. Publications per year.

For instance, authors in [45] introduced an innovative IoT-based diabetes management system with the purpose of enhancing mobile assistance services. Their system aimed to mitigate the risks associated with insulin therapy, reducing the incidence of hypoglycemia and hyperglycemia episodes among patients. Authors in [46] explored the concept of pervasive healthcare in smart communities, emphasizing the deployment of wireless body sensors to monitor environmental conditions and the health status of community members. These seminal studies not only demonstrated the feasibility and potential of IoT in healthcare, but also sparked a surge of research exploring diverse applications and improving healthcare delivery through innovative technological solutions.

TABLE III. MOST PRODUCTIVE JOURNALS

Journal	No of publications	%
IEEE Access	264	28%
IEEE Internet of Things Journal	195	21%
Sensors	140	15%
Future Generation Computer Systems	89	9%
Wireless Communications and Mobile Computing	46	5%
Electronics	46	5%
IEEE Transactions on Industrial Informatics	45	5%
Wireless Personal Communications	41	4%
Journal of Healthcare Engineering	41	4%
Journal of Medical Systems	37	4%
	944	100%

B. Academic Institutions, Countries, and Authors with the Highest Levels of Productivity

Kumar, N. and Rodrigues, JJPC stand out as the most productive scholars on the subject of IoT implementation in healthcare literature, with 31 and 25 publications, respectively, according to Table IV. The IoT and its potential usage in healthcare are the primary areas of their research. Among Kumar, N.'s notable contributions to healthcare IoT integration with blockchain, AI, and fog computing, is his substantial work in this area, as can be seen in Figure 3. His research shows the revolutionary potential of these technologies to enhance healthcare delivery and patient outcomes.

TABLE IV. MOST PRODUCTIVE AUTHORS

Author	Number of publications	%
Kumar, N.	31	15%
Rodrigues, JJPC.	25	12%
Guizani, M.	23	11%
Gupta, D.	20	10%
Ray, P.P.	19	9%
Sood, S.K.	19	9%
Choo, K.K.R.	17	8%
Hossain, M.S.	17	8%
Muhammad, G.	17	8%
Das, A.K.	15	7%

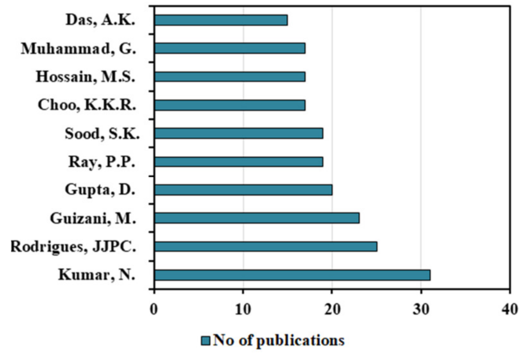

Fig. 3. Most published authors.

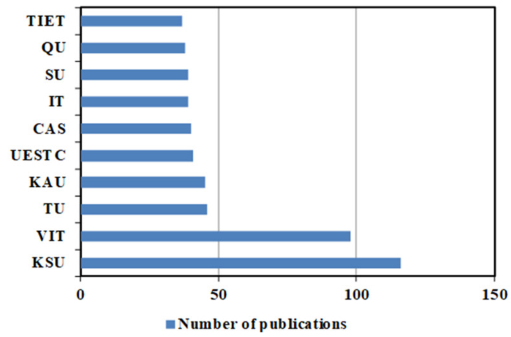

Fig. 4. Academic institute-based number of publications.

In the realm of bibliometric analysis focusing on the IoT applications in healthcare, King Saud University, based in Saudi Arabia, emerges as a leading institution with 116 publications, followed closely by Vellore Institute of Technology in India, with 98 publications, as evidenced in Figure 4 and Table V. This dominance underscores the significant presence of Saudi institutions, which occupy three of the top four positions. The global landscape is also shaped by India and China, each contributing significantly with multiple entries in the top ranks of productive institutions.

TABLE V. MOST PRODUCTIVE ACADEMIC INSTITUTES

Institute	No of publications	Country
King Saud University (KSU)	116	Saudi Arabia
Vellore Institute of Technology (VIT)	98	India
Taif University (TU)	46	Saudi Arabia
King Abdulaziz University (KAU)	45	Saudi Arabia
University of Electronic Science and Technology of China (UESTC)	41	China
Chinese Academy of Sciences (CAS)	40	China
Institution de Telecomunicaçoes (IT)	39	Portugal
Sejong University (SU)	39	South Korea
Qatar University (QU)	38	Qatar
Thapar Institute of Engineering & Technology (TIET)	37	India

The broader view presented in Table VI and Figure 5 highlights India as the most prolific country with 793 publications, followed by China with 634. Notably, the majority of countries and institutions are from developing regions, underscoring the robust support and advancement of IoT applications in healthcare within these economies. Saudi Arabia, for instance, sees nearly two-thirds of its publications originating from its top three institutions, further illustrating concentrated institutional contributions. Overall, the prevalence of Asian countries, observed in Table VI, reinforces their substantial role in driving research and innovation in the IoT healthcare applications globally.

TABLE VI. MOST PRODUCTIVE COUNTRIES

Country	Number of publications	%
India	793	25%
China	634	20%
Saudi Arabia	334	10%
USA	332	10%
South Korea	243	8%
Pakistan	235	7%
UK	229	7%
Australia	166	5%
Italy	116	4%
Malaysia	116	4%

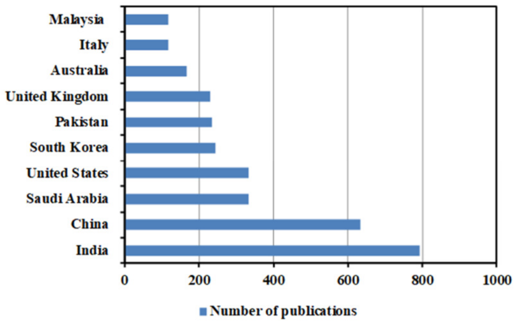

Fig. 5. Most productive countries.

C. *Keyword Frequency and Citations*

Table VII and Figure 6 outline the 20 most common keywords. IoT, healthcare, and IoHT are the most common topics, mainly because these terms are intentionally included in search queries. Phone conversations, in-person visits, and emails were the usual ways for patients to get in touch with healthcare professionals until the IoHT came along. Unfortunately, these solutions were unable to enable real-time health monitoring or tracking due to the lack of smart devices and the associated infrastructure. The development of the IoT had a revolutionary effect on the medical field. The healthcare system was made easier with this technology and patients may be monitored and treated in real-time. Innovations, such as telemedicine, internet consultations, and real-time monitoring, demonstrate this change. Above all else, the keyword "Security" stands out, highlighting how important it is to protect patients' private health information. Thus, in order to avoid possible legal and ethical issues related to the disclosure of sensitive patient information, it is imperative that healthcare IoT apps prioritize strong data security and privacy safeguarding during their development.

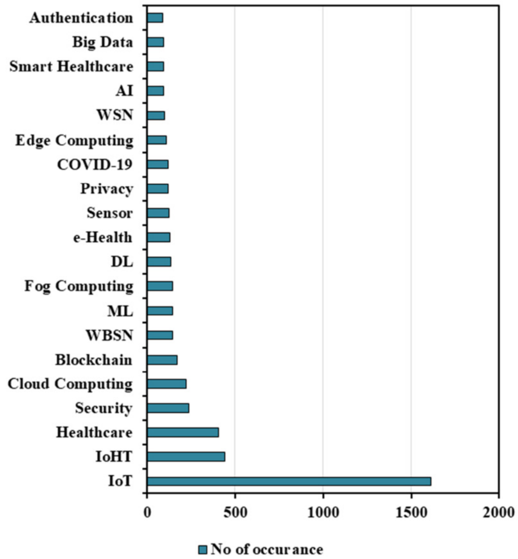

Fig. 6. Keyword-based number of occurrences.

TABLE VII. TOP 20 MOST USED KEYWORDS IN IOT-BASED HEALTHCARE STUDIES

Keyword	Occurrences
IoT	1612
IoHT	442
Healthcare	407
Security	237
Cloud Computing	222
Blockchain	172
WBSN	146
ML	146
Fog Computing	144
DL	135
e-Health	131
Sensor	122
Privacy	119
COVID-19	117
Edge Computing	107
WSN	97
AI	96
Smart Healthcare	96
Big Data	94
Authentication	90

Big data, cloud computing, blockchain, ML, fog computing, edge computing, AI, and Wireless Body Sensor Networks (WBSN) have all revolutionized the healthcare system. Faster, more efficient, and better therapy is now possible thanks to these technologies, which considerably increases patient satisfaction [49]. By combining cloud computing with IoT, operational performance can be improved in the face of increasing demand by making shared medical data and on-demand services more transparently accessible [45]. Secure medication tracking, remote patient monitoring, and simplified medical record management are just a few ways in which blockchain technology improves healthcare systems. Carers can electronically observe patients with little impact on their everyday lives using WBSN-based devices. This allows them to receive greater insights into health problems and reduce errors by monitoring important physiological indicators, like glucose concentrations and pulse rates, in real time. IoT devices have been vital in the healthcare monitoring during the COVID-19 epidemic, quickly notifying users of possible health problems [48].

At the forefront of IoT and healthcare research, Table VIII showcases the most influential papers that have shaped the field, predominantly through comprehensive reviews. These seminal works have not only advanced people's understanding of IoT applications in healthcare [49], AI's transformative impact on medical practices [50], and the efficacy of WBSN [51], but have also explored broader topics, involving blockchain technology applications [52] and critical IoT challenges, such as security and privacy [46]. Furthermore, the global COVID-19 pandemic has emerged as a focal point, drawing substantial scholarly interest and contributing significantly to the discourse [53]. These papers collectively represent pivotal contributions that have accelerated the diffusion of knowledge in the IoT applications within the healthcare domain, underscoring their enduring impact on research and practice, alike.

TABLE VIII. TOP 10 MOST CITED PUBLICATIONS

Reference	Title	Citations
[49]	The Internet of Things for health care: A comprehensive survey	3229
[53]	The SARS, MERS and novel coronavirus (COVID-19) epidemics, the newest and biggest global health threats: what lessons have we learned?	1966
[54]	Monitoring of Vital Signs with Flexible and Wearable Medical Devices	1335
[52]	A systematic literature review of blockchain-based applications: Current status, classification and open issues	2474
[55]	An IoT-Aware Architecture for Smart Healthcare Systems	1320
[56]	Sensor mania! the internet of things, wearable computing, objective metrics, and the quantified self 2.0	1388
[46]	A Survey on Security and Privacy Issues in Internet-of-Things	1335
[57]	Exploiting smart e-Health gateways at the edge of healthcare Internet-of-Things: A fog computing approach	1285
[51]	Multi-sensor fusion in body sensor networks: State-of-the-art and research challenges	960
[50]	Artificial Intelligence (AI) applications for COVID-19 pandemic	1599

IV. NETWORK ANALYSIS

A. *Analyzing the Co-Occurrence of Keywords*

Based on the keyword co-occurrence analysis of IoT's impact on the healthcare sector, several distinct research clusters have emerged, as displayed in Figure 7, revealing the diverse applications and potential of the IoT in this field. The largest cluster, highlighted in red, focuses on the IoT technologies, like Wireless Sensor Networks (WSNs), Radio-Frequency Identification (RFID), and various sensors, revolutionizing healthcare delivery. These technologies are crucial in advancing e-health, telemedicine, and mobile healthcare (mHealthcare) by facilitating patient participation, illness self-management, and remote doctor follow-up. For instance, wearable sensors and smartphone-based health monitoring systems enable continuous patient observation even after hospital discharge, enhancing chronic illness management and improving overall health outcomes [68, 69]. This cluster underscores the transformative potential of the IoT in creating smart healthcare solutions within smart city frameworks, where Information and Communication Technology (ICT) is integrated into traditional city infrastructure to improve coordination and efficiency in healthcare delivery.

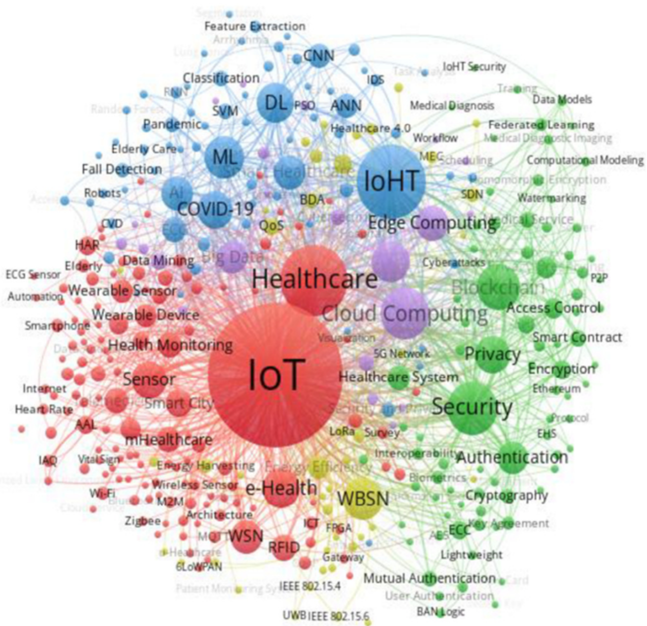

Fig. 7. Keyword co-occurrence network.

Another significant cluster, represented in green, revolves around the application of blockchain technology in the IoHT, particularly its role in enhancing security and privacy. Blockchain's decentralized nature and robust encryption methods, such as digitally signed transactions and public key infrastructure, address the limitations of centralized healthcare databases, which often suffer from performance bottlenecks and single points of failure [70]. This cluster highlights blockchain's potential to improve drug traceability, simplify patient monitoring, and secure the storage and distribution of patient information among healthcare providers. Additionally, other clusters delve into the use of AI in processing vast amounts of IoT-healthcare data, the role of 5G networks in supporting IoHT applications with high bandwidth and low latency, and the significance of cloud, fog, and edge computing in meeting the computational and storage demands of the IoT-based healthcare systems. Collectively, these clusters illustrate how different technological paradigms are converging to reshape healthcare practices, promising significant advancements in patient outcomes, healthcare costs, and the overall efficiency of the healthcare systems.

B. Co-Citation Network

The co-citation network analysis applied to the field of IoT and healthcare began by setting a threshold of five for both citations and co-citations, resulting in the exclusion of disconnected nodes. This stringent approach distilled the initial pool of 2990 articles to 629 core articles, effectively removing 2361 articles that did not meet the criteria. The refined network was then analyzed using Gephi's modularity tool, which employs the Louvain algorithm to optimize the modularity index—a measure indicating the strength of the division of the network into clusters. The resultant modularity index of 0.811 suggests a robust clustering, with seven distinct clusters being identified [71]. Each cluster represents a group of articles that are densely interconnected, sharing significant co-citation relationships, which indicate a common interest and research focus within the field.

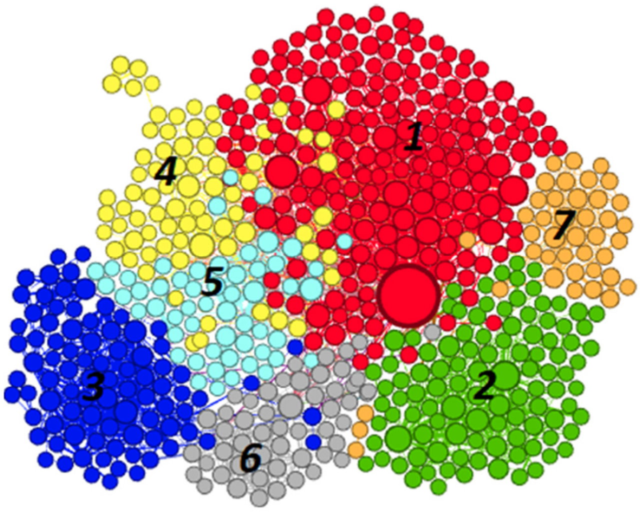

Fig. 8. Co-citation network.

The identification and examination of these clusters provide valuable insights into the structural and thematic composition of the co-citation network. Each cluster, characterized by high internal connectivity and relatively weaker links to other clusters, encapsulates a specific area of research within IoT and healthcare. By having focused on the top ten articles within each cluster, researchers were able to pinpoint key research hotspots and leading articles that define each cluster's primary interests. The high modularity index underscores the relevance and strength of these connections, reflecting significant thematic cohesion within clusters. The detailed analysis of the leading articles from each of the seven clusters, as seen in Figure 8, reveals the major research interests and trends, offering a comprehensive overview of the IoT and healthcare research landscape while, also, enabling further exploration into specific areas of high impact and collaboration within this interdisciplinary field.

V. OPEN RESEARCH AREAS

It is of the utmost importance that the many IoMT devices being now under development for health tracking and monitoring be adapted to each person's unique requirements. For instance, in developing monitoring and tracking systems for care facilities based on the IoMT, it is important to keep the needs and preferences of the elderly in mind [72]. Due to the fact that many older people do not like wearing electronics, it is necessary to employ discreet equipment in order to collect all necessary data without disturbing them. Involving end-users in the project from the beginning is crucial in solution design and development. It is critical to get user input early on in the requirements-gathering process, and that involvement should persist throughout the project's lifetime to ensure constant feedback. Participation from users improves the system's suitability for their requirements and tastes, which in turn enhances user experience. Being particularly important for less developed nations, most studies fail to account for the expenses connected with the IoMT projects. Component, implementation, and maintenance costs must be considered in real-world and commercial IoMT utilization [72]. There has to be more cooperation between developed and developing nations to find affordable solutions, as this area of study is predicted to expand. To enhance the understanding of the implementation, applications, benefits, and limitations of the IoMT, future research should place a greater emphasis on case studies.

VI. CHALLENGES

The purpose of this bibliometric study was to improve the academic knowledge of the utilization of IoT in healthcare by analyzing the evaluated literature for keyword frequency. This method uncovered the gigantic untapped potential of the IoT for creating intelligent, efficient, and individually tailored healthcare systems. Modern advancements in the IoT integration have been recently brought to light by studies highlighting the use of blockchain, cloud computing, AI, and WBSN. The potential benefits of these connections in healthcare include better diagnosis, more precise treatment suggestions, more thorough physiological data collection, and lower overall healthcare expenses. Influential works and seminal articles in this area inform current thinking, pave the way for future collaboration, and suggest avenues for a groundbreaking study. Analyzing the co-occurrence of keywords in healthcare research on the IoT revealed common threads, including e-health, health monitoring, and telemedicine, highlighting the importance of IoT in forwarding smart city projects. Investigating how the IoT interacts with e-health, telemedicine, and healthcare architecture is an important area for future study. Another area that could benefit from IoT is its ability to make public health prevention, and secondary and tertiary treatment more proactive, continuous, and integrated. There are still a lot of unanswered questions about handling data management, interoperability, security, privacy, patient and professional acceptance, and other issues related to healthcare that are based on the IoT, despite the fact that many applications seem promising. In order for healthcare organizations to embrace the IoT, there must be legislative backing, cybersecurity requirements, and careful planning [73]. Additionally, blockchain technology has emerged as a solution to enhance the IoT implementation by ensuring data security, transparency, and efficiency in healthcare. Future studies should evaluate blockchain-IoT systems to provide real-world security assurances and explore tokenization for cost reduction. Research should also focus on improving blockchain throughput, consensus protocols, and the development of quantum computing-resistant digital signatures. The convergence of AI and IoT, the potential of 5G in healthcare, and the development of secure IoT solutions for smart medical equipment are critical areas for future exploration. Co-citation network analysis further highlights essential research topics, such as IoT security authentication, fog computing, and cognitive smart healthcare, providing a roadmap for future investigations in this transformative field.

VII. CONCLUSIONS

The current paper outlines a complete and methodical approach to bibliometric analysis through the use of data from seven main databases and a variety of technologies that reduce the need for manual labor. Researchers can greatly benefit from this methodology because of its adaptability and the range of fields in which it can be used. By analyzing the Internet of Medical Things (IoMT) bibliometrically, a great amount of knowledge can be obtained about the research trends and advancements in this area over the last decade, which is useful for evaluating this methodology. The present study avoids the subjective biases common with conventional methods by obtaining objective results through the use of several bibliometric methodologies. Academics, legislators, and healthcare practitioners can all benefit from the analysis, which not only charts the present status of the IoMT research, but also identifies unexplored areas that need additional investigation.

An extensive analysis of the healthcare IoT research was conducted by reviewing 2,990 documents from the Scopus database, covering nearly 12 years. The data show that there has been a dramatic uptick in publishing since 2017, with most of the articles appearing in prestigious journals related to computer science, such as Sensors, IEEE Internet of Things, and IEEE Access. As a result, these publications play an essential role in promoting healthcare-related IoT research. Notable scholars in this area are N. Kumar and JJPC Rodrigues whereas the top university in this discipline is King Saud University. The majority of the research is carried out in Asian countries, and mostly in Pakistan, China, India, and Saudi Arabia although the UK and Italy have made significant contributions. The study presents a thorough overview of the important trends and themes in this interdisciplinary field by identifying seven research clusters based on co-citation networks and five clusters based on keyword co-occurrence.

DATA AVAILABILITY STATEMENT

Data are available upon suitable demand.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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