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Review article

The applications of internet of things in smart healthcare sectors: a bibliometric and deep study

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ABSTRACT

The recent attention garnered by Internet of Things (IoT) technology for its potential to alleviate challenges faced by healthcare systems, such as those resulting from an aging population and the rise in chronic illnesses, has underscored the significance of smart healthcare. Surprisingly, no bibliometric study has been conducted on this subject to date. Consequently, this investigation aims to provide a comprehensive overview of the longitudinal state and knowledge structure of IoT in smart healthcare. To achieve this, a content analysis tool is employed for academic research, facilitating the identification of key study themes, the growth trajectory of the research topic, the top journal sources, and the distribution of nations based on subject areas. The bibliometric evaluation encompasses 614 publications published in 14 journals spanning the period from 2016 to 2022. Employing bibliographic coupling analysis, the latest developments in IoT have been uncovered within the domain of smart healthcare. The findings reveal 11 primary research topic areas that have been the focus of scholarly discourse during this period. This study highlights that the computing paradigm and network connectivity emerge as the most prominent topics within this research domain. Blockchain-based security in healthcare closely follows as the second-largest topic discussed by scholars. Additionally, the analysis indicates a significant increase in total publications for the most popular topic, peaking around 2018.

1. Introduction

The existing medical and healthcare services are severely challenged by the growing number of chronic patients and the aging population, necessitating the integration of healthcare with emerging information and communication technologies (ICT) to improve services [1,2]. In the evolving healthcare landscape, the upcoming health sector is poised to address the challenges posed by a rising population of chronic patients and the limited availability of treatment options to meet the escalating demands of patients [3,4]. A pertinent illustration of this transformation can be observed in the response to the global COVID-19 pandemic [5]. Leveraging state-of-the-art technology within healthcare systems and implementing proactive protective measures hold the potential to facilitate the early identification of potential health issues; this, in turn, enables the prompt scheduling of essential interventions, including the continuous monitoring of treatments and the development of innovative assessments [6].

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The term 'smart healthcare' refers to platforms for health systems that utilize gadgets like wearable electronics, the Internet of Things (IoT), and mobile Internet to connect people, resources, and organizations, making it simple for patients to submit health records [7–9]. Besides, cloud computing and IoT in healthcare refers to a combination of medical tools and software communicating with healthcare IT systems over Internet computer networks [10–13]. IoT and cloud computing enable machine-to-machine connections through Wi-Fi-enabled medical devices, establishing the groundwork for a seamless data-sharing and analysis system [14–16]. Using IoT in smart healthcare, a patient's body parameters can be measured in real-time [17]. Personalized treatment, real-time data-driven decision-making, and remote patient monitoring are all made possible by IoT, which is currently revolutionizing the healthcare industry. The actors involved in intelligent medical treatment are broad and include doctors, personnel, hospitals, and research organizations [18]. Since the integration of healthcare services and IoT, numerous new applications have been created for various contexts, with devices with sensors being one of the examples [19]. The majority of vital applications for the present or the foreseeable future use these devices. Several body-sensing devices have been created for ongoing healthcare, fitness, and physical activity awareness monitoring [20].

Furthermore, IoT in smart healthcare enables powerful and effective connections in examining patients' conditions and predicting their health status. With real-time smart healthcare data facilities, providing information on the examination of patients becomes easier, improving human health status rather than relying solely on treatment after sickness [21]. During the pandemic, real-time IoT solutions effectively saved lives by addressing illnesses such as heart failure, diabetes, high blood pressure, and asthma attacks. This fact highlights the importance of IoT in enhancing healthcare services [22]. Smart medical equipment is connected via a smartphone to send relevant patient data to the doctor effectively [23]. These devices also capture data on blood pressure, oxygen levels, sugar levels, weight, etc. Hence, it can be said that things have significantly changed since IoT was involved in the healthcare sector. Not only does it alleviate overall stress on the healthcare infrastructure, but it also allows for real-time tracking and patient assistance [24]. The use of telemedicine, online/real-time monitoring, and consulting are only a few instances of how this crucial transition manifests [25].

IoT-based solutions for medical applications are being developed by an increasing number of academics and companies to fully leverage the possibilities of IoT in healthcare systems. This investigation aims to provide a bibliometric analysis of facilitating technologies and smart healthcare in IoT, as well as a summary of the development of state-of-the-art studies in IoT in smart healthcare systems [26,27]. Bibliometrics is a quantitative analysis of publications that aims to ascertain a certain type of phenomenon. The process of written communication and how it has evolved within a scientific discipline can be explained by bibliometrics. Collaboration of researchers to conduct tasks to investigate a certain research issue will result in progress and knowledge development. Of course, it is vital to review the results of prior scientific investigations that colleagues also carried out.

It is advised that some publications should exist to present knowledge output in the input-output model used in classical literature to explain the process of scientific inquiry. Nearly every publication in the form of a monograph or a scientific article will be accepted as an official declaration of the findings of the research. This study will benefit readers and researchers in smart healthcare and IoT to fill gaps and complement bibliometric literature analysis in the field.

Finally, the structure of the paper is arranged as follows: Section 2 briefly summarizes the existing literature in the IoT and smart healthcare field. Section 3 focuses on the methodology of the research. Section 4 provides the results and discussion. Section 5 offers the conclusion of this study.

2. Literature review

IoT in smart healthcare research has been examined using a variety of methodologies in the literature that are now available. Investigators frequently used manual content or co-citation analysis to disclose a study subject's state or determine its trend. The research methodologies, resources, data sources, and findings from earlier studies that are relevant to the current investigation are explained in the following paragraphs.

An early work by Bui and Zorzi [28] indicated that IoT could become the main enabler for distributed worldwide healthcare applications. They identified the requirements of a unified communication framework. Their work might serve as a springboard for further attempts to organize the review of current IoT in smart healthcare literature.

Islam, Kwak [29] conducted an extensive study to examine the development of IoT-based healthcare technologies and assess the most recent network topologies and applications, platforms, and market trends. Additionally, they attempted to assess the various IoT security and privacy characteristics. Their research filled a knowledge gap about the diverse IoT and eHealth regulations and policies throughout the world. Additionally, the authors made an argument for the unresolved problems and difficulties to aid future researchers in their work on IoT-based healthcare services.

In a similar vein, Yin, Zeng [30] carried out a thorough study to determine the IoT applications in the healthcare sector as well as the trend and course of future research in this field. The authors of their paper's thorough literature research discovered that the expansion of IoT in the healthcare system was investigated from the standpoint of enabling technologies and techniques. Additionally, writers made the case that an increasing number of academics and businesses focused on creating IoT-based solutions for medical applications. To deliver an exhaustive assessment of the capabilities of enabling technologies and smart healthcare devices within the IoT realm, the authors were motivated to delineate the progression of cutting-edge research pertaining to healthcare systems embedded in IoT. They appropriately included future trends and directions for the field's future study.

Bamidis [31] reviewed 778 articles retrieved from the Web of Science (WOS) to reveal the trends and themes and the future hints for the next research in this research field. The authors combined the method of bibliometrics analysis and text mining, where it is mentioned in the paper that text mining can complement bibliometric analysis and fulfill the need for faster content analysis and categorization. Their study used BibExcel to calculate co-occurrence and used Pajek for visualization. Meanwhile, it was performed using WordStat for text mining and clustering analysis.

Conducting an SLR, Ahmadi, Arji [32] sought to uncover pivotal insights into the utilization of IoT within the healthcare sector. Their study encompassed an exploration of several key facets, including the principal application domains of IoT in healthcare, the most notable IoT technologies, the constituent elements of IoT architecture as applied to healthcare, the characteristics of cloud-based design, security, and interoperability concerns within IoT architecture, as well as the consequential effects and challenges posed by IoT in healthcare. The analysis encompassed a comprehensive review of 60 relevant articles spanning the period from 2000 to 2016. Notably, the authors emphasized that one of the foremost applications of IoT in healthcare is the provision of home healthcare services. Furthermore, based on their findings, the authors emphasized that privacy and security issues were the biggest obstacles to IoT in healthcare.

Usak, Kubiatko [33] used a similar approach to give comparison data and analyze the most recent advancements in IT-based technologies like IoT and cloud computing in the healthcare service. Additionally, the paper's authors covered the disadvantages and advantages of the evaluated mechanisms along with their primary obstacles in the development of future IoT strategies for healthcare services.

Sadoughi, Behmanesh [34] examined 89 publications found in WOS, IEEE Xplore, Scopus, and PubMed to identify and map the most recent IoT innovations in medicine. Three different strategies were used in their investigation. First, the publications from the database were between 2000 and 2018. They secondly pre-processed the acquired definitional data to extract the conceptual components of a linked study subject based on key phrases and keywords. In order to locate relevant publications published in the aforementioned database, their investigation comprised subjecting key phrases, titles, and abstracts from the sample database. The authors recommended doing a taxonomy study to establish a specific definition for some words to assist researchers in using them correctly in scientific writing based on the research findings.

In Singh, Kumar [35], the investigators used network analysis together with bibliometric analysis. The IoT-related publications for smart healthcare were comprehensively reviewed using the composite research technique. There were 1000 documents to analyze. The top ten universities by affiliation, top ten authors, top ten nations, top ten sources, top ten financial sponsors, and subject-wise classification were among the factors that were studied. In addition, network analyses of keywords, source citations, author co-citations, and country-based co-authorship were performed. According to the report, assisted living for elderly people and health monitoring technologies might be the major topics in the future. Furthermore, the authors made the case that more studies in this field would be anticipated in the upcoming years, necessitating closer cooperation between developed and developing nations.

All of the aforementioned research employed manual content analysis, which involved a thorough review of the articles and the utilization of analytical tools such as Pajek, BibExcel, and Wordstat. The technique employed in this present paper is distinctive in order to mitigate the laborious, time-consuming, and potentially problematic issue of coder disagreements. To broaden the scope of our sample, we endeavored to collect as many IoT-related papers as possible. Additionally, because MSC (Main Subject Categories) was required for the analysis and was not available in other tools, the authors of this study opted for Tseng [36]'s analytical tool to conduct bibliometric analysis. CATAR, an automated content analysis tool, provides a summary of the scientific background gleaned from the analysis. Consequently, CATAR empowers this investigation to identify the most important study themes in IoT-related literature related to healthcare, track research developments, identify top authors and nations, and pinpoint the most frequently referenced sources. These insights were seldom disclosed in prior review studies.

3. Methodology of research

As a quantitative approach, academics have used the bibliometric method to investigate the relationship between bibliographic data in the field and to identify connections between works cited and those cited in relation to measuring and assessing science. Quantitative methodologies were highlighted in previous research using various bibliometric techniques, including co-citation analysis, co-word analysis, and bibliographic coupling (BC) analysis. The BC analysis recommended in this study will be implemented using bibliometric clustering and mapping with CATAR [37,38]. The specific steps taken for the implementation of scientometric analysis using bibliometric clustering and mapping are as follows.

3.1. Data collection

The data collection stage was conducted in the initial phase, and for the following reasons, data were obtained from ISI WOS. Firstly, it is crucial to note that WOS is a citation database indexing the details of each research article's bibliography and the references it cites. In 2016, WOS included more than 13 million bibliographic data and over a million articles from more than 7000 publications. Secondly, WOS provides a rational, impartial method for swiftly finding relevant information. Thirdly, WOS offers standardized references that can be utilized in BC analysis to find comparable individuals [39]. Additionally, exclusion and inclusion criteria were established to tailor the search queries for obtaining highly relevant literature. Initially, a list of words was compiled for use as search phrases. Phrases related to the IoT in the smart healthcare domain were focused on to discover relevant literature, including terms like "Internet of medical things," "Internet of healthcare things," "smart healthcare," and "IoMT." Exclusion criteria were concurrently created to filter out papers not pertinent to the main problem or published in languages other than English. Conference papers, proceedings, and books were also excluded from the study, and the criteria for including full-length papers were restricted due to their offering extensive bibliographic information suitable for supporting BC analysis.

To ensure quality, homogeneity, and academic rigor, preliminary research in technical reports, editorials, comments, and consulting papers was excluded. The foundation for BC analysis is bibliographic data; therefore, only research publications were downloaded, and book reviews, study notes, and conference papers were not included. The collection of records spanned seven years, from 2016 to the beginning of 2022. On November 22, 2022, complete text file records, containing abstracts and referenced references, were downloaded. The final collection of sources comprised 1830 papers. Each bibliographic record includes fields such as authors (AU), publication year (PY), title (TI), number of citations (TC), journal title (SO), cited references (CR), and publication abstract (AB).

3.2. Text segmentation

There were around 40 fields per example article record, including the authors, title, addresses, publishing dates, etc. Seven of them were chosen by the authors for analysis. The document contained the following acronyms, definitions, and examples [37].

- AU: authors, e.g., Baker, SB.
- TI: title, e.g., IoT for smart healthcare: Technologies, challenges, and opportunities.
- SO: journal title, e.g., IEEE Access.
- AB: publication's abstract.
- C1: first author's country (extracted from the first author's address in the original C1 field).
- CR: normalized citations, e.g., Ding and Wang, 2022, IEEE IoT J, V9.
- PY: publication year, e.g., 2022

3.3. Similarity computation

CATAR performs a similarity computation after identifying each record using comparable citations standardized within individual citations. It starts by defining document characteristics and determining the similarity of articles based on those attributes before clustering the documents. The anticipation is that the references included in each article will serve as the document's characteristics, acting as sub-disciplines for a study subject in the development of document clustering. Then, commonalities between each set of articles are determined using normalized common features.

3.4. Multi-stage clustering (MSC)

Using clustering analysis, groups are formed where objects are more similar to one another than to those in other groups. The algorithm initially assigns each item to a single cluster, following the concept of clustering. Subsequently, the most equivalent pair of clusters (with a similarity greater than a threshold) is employed to build larger clusters. This process is iterated until no further clusters can be combined. This recurrent grouping procedure is known as multi-stage clustering (MSC).

3.5. Cluster labeling

After that, cluster labeling is performed. Using the clustering analysis, the CATAR algorithm will derive the sub-topic, indicating that the articles have already been categorized into clusters. Additionally, researchers need to locate the titles or abstracts of each cluster to understand the contents of a cluster. To quickly identify the topics of each cluster, researchers employed a text-mining approach for the autonomous extraction of cluster descriptors [37].

3.6. Facet analysis

Once the topics have been identified, performing cross-tabulations with data from other facets becomes a straightforward process. This method of cross-analysis often yields a wealth of information surpassing that obtained through single-facet analysis alone. Rather than simply gauging their output, it becomes possible to discern how topics are distributed across all authors, thereby shedding light on the primary areas of their expertise. One quantifiable method to gauge topic trends is by assessing the slope of the linear regression line that best fits the time series data. Additionally, it is also feasible to document the annual distribution of articles for each topic in the time series. These analyses serve as the primary focus of this study and highlight the key distinctions between this study and others.

3.7. Visualization

Multidimensional scaling (MDS) mapping was used to depict the CATAR-detected knowledge structure. The precise Euclidean space dimensions, often two or three for easy visual interpretation, are determined by the MDS approach for each topic. A topic map is created using these coordinates to easily illustrate comparative information between each cluster, such as relative cluster size, inter-cluster proximity, and geographic topic distribution [40]. The corpus can be explored in various ways thanks to its representation. It will be displayed in the topical map, which illustrates relationships between the topics found in a two-dimensional area. The study's understanding of the cluster interaction by distance and orientation might benefit from it.

4. Results

The obtained results are presented in detail in this section.

4.1. Subject areas

Using automatic content analysis, 11 categories and 26 subtopics emerged from the articles retrieved from WOS from 2016 to 2022. As shown in Table 1, the results were manually labeled following the studies of [36,40]. They were labeled by theme based on the descriptors of subtopics as follows: (i) computing paradigm and network of connection (CPNC); (ii) data transmission system (DTS); (iii) IoT communication model (IOTCM); (iv) certificateless signcryption on the Internet of health things (CSIOHT); (v) security and privacy of IoMT (SPIOMT); (vi) technology innovation of communication (TIC); (vii) advanced network (AN); (vii) privacy of the patient (PP); reinforcement of blockchain technology (RBT); (x) Blockchain-based security in healthcare (BSH); (xi) smart healthcare in diagnosis and detection (SHDD). As elucidated in the research methodology section, these 11 clusters emerged organically from various subclusters. Take, for instance, the CPNC cluster, which encompasses five distinct subtopics. Within its initial subtopic, a total of 45 documents have been consolidated, centering around themes such as edge computing, cloud computing, cloudlet computing, and IoT. Furthermore, the subtopics pertaining to the offloading system, edge computing, task allocation, and computation have garnered substantial attention from scholars, reflecting their significant contributions to this particular field of study.

The issue of CPNC may be regarded as the major study topic in the IoT in the field of smart healthcare, as shown in Table 1. Between 2016 and 2022, 296 papers were published. BSH was the next subject, accounting for 14.3 % of all papers. IOTCM was placed fourth, followed by DTS in third place. Finally, little study was done on CSIOHT, AN, PP, and SHDD. It should be emphasized that the significant portion of CPNC is because it contains many subtopics, many of which have more in common with one another than the other 10 subject groups.

The 11 topics cover 614 articles of the original 1833; 1219 articles were removed as outliers during the MSC. The outliers during the MSC mean those articles deal with an independent and probably less-noticed issue. These articles are distributed throughout many tiny clusters, a behavior that parallels the long-tail effect seen in data on online book sales. It is also possible that these tiny clusters are

Table 1
Topic categories extracted from WOS.

Abbreviation	Topics	Documents	Subject areas	Subtopics (Number of articles grouped in the subtopics)
CPNC	Topic 1 Five subtopics	296	Computing paradigm and network of connection	• Edge computing, cloud computing, cloudlet computing, and IoT (45) • Fog, edge computing, cloud computing, and survey (35) • The offloading system, edge computing, task, and computation (140) • Thing, IoT, computation, edge computing, and IoT (38) • Data injection, Internet of Things, distributed edge and container (38)
DTS	Topic 2 Three subtopics	42	Data transmission system	• Delay, minimum, cache-enabled, allocation, and deployment (7) • Mobile edge, offloading system, computing, transmission, and computational (18) • The offloading system, computation, mobile edge, and allocation (17)
IOTCM	Topic 3 Two subtopics	32	IoT communication model	• Federate learning, communication-efficient, model and device (23) • Federate, IoT edge, edge (9)
CSIOHT	Topic 4 Two subtopics	20	Certificateless signcryption on Internet of Health Things	• Certificateless signcryption, authentication, and signature (12) • Id-based, signcryption, scheme, and Internet of Health Things (8)
SPIOMT	Topic 5 Two subtopics	29	Security and Privacy of IoMT	• Authentication, user, protocol, and scheme (20) • The scheme, IoMT, communication, authentication, and security (9)
TIC	Topic 6 Two subtopics	26	Technology innovation in communication	• Latency-optimal and QoS-driven (8) • Mobile edge computing and NOMA-enabled (18)
AN	Topic 7 Two subtopics	15	Advance network	• Grid mobile edge computing (**GMEC**), vehicular network, multi-mec-server, and time-varying (4) • An edge-cloud computing system, offloading system, and task offload (11)
PP	Topic 8 Two subtopics	21	Privacy of patient	• Artificial intelligence, survey, analytics, and edge intelligence (7) • Deep, inference, cancer, privacy-preserving, and edge-cloud computing system (14)
RBT	Topic 9 Two subtopics	24	Reinforcement of blockchain technology	• Contract, blockchain, deduplication, finite-lifetime, edge chain (8) • Blockchain, resource, reinforcement (16)
BSH	Topic 10 Two subtopics	88	Blockchain-based security in healthcare	• Blockchain, blockchain-based, security, healthcare, and framework (32) • Edge computing, blockchain-based, systems, and IoT (56)
SHDD	Topic 11 Two subtopics	21	Smart healthcare in diagnosis and detection	• Pathology, detection, face recognition, voice pathology detection (8) • Smart healthcare, edge-stream, disease, medical, and diagnosis (13)

made up of pieces from different fields whose citation styles do not correspond to those used in tourist research, meaning they do not correspond to the key issue areas. The articles in these tiny clusters are intriguing because they can be viewed as papers that, by referencing fresh material, provide new understanding and creativity to the field of tourism.

4.2. Characteristics of subject areas

Circles in Fig. 1 represent thematic clusters, and the size of the circle corresponds to the number of articles categorized under each topic. The geographic relationships between these themes based on BC similarity are depicted in Fig. 1. The geographical linkages between the circles show that they have similar citation patterns and cover related themes. According to Fig. 1, the prominent IoT subject for smart healthcare is CPNC. It is the largest circle, with 296 articles, and it contains a circle called SHDD, indicating that the topics in SHDD are tightly connected to those in CPNC based on citation patterns. Additionally, the topics of TIC, IOTCM, SPIOMT, and CSIOHT overlap, suggesting a close relationship between these topics.

Fig. 1 further shows that the research topics of BSH, TIC, IOTCM, SPIOMT, CSIOHT, DTS, SHDD, and CPNC have relatively closer relations. On the other hand, the research of IoT in smart healthcare in the AN subject area is closer to the eight subject areas mentioned before, even though it is not close to them. However, PP and RBT are more distinct subject groups that do not overlap or have any connections to other topics. Based on the magnitude of the various subject areas, Fig. 1 clearly illustrates the popularity of each issue and the researchers' primary areas of interest. Without question, studies relating to CPNC have garnered the most interest. Studies on this subject seek to create an advanced network to enhance communication by implementing an advanced system to deliver high-quality healthcare services, ensuring satisfaction from both the supply and demand perspectives.

The subject consists of five subtopics, including (i) edge computing, cloud computing, cloudlet computing, and the Internet of things; (ii) fog, edge computing, cloud computing, and survey; (iii) offloading system, edge computing, task, and computation; (iv) thing, Internet of things, computation, edge computing, and IoT; (v) Data-injection, Internet of things, distributed edge and container. Specifically, offloading systems, edge computing, task, and computation were the most published subtopics, followed by edge computing, cloud computing, cloudlet computing, and the IoT. This finding demonstrates that the topic of this study mainly focuses on the system and computing network field.

The second-largest topic, BSH, has two subtopics and includes research on the demand for blockchain-based security systems [41]. The subtopics imply that research endeavors have concentrated on blockchain-based IoT integration to support consumers' secure smart healthcare. Being closely related to CPNC, studies clustered in SHDD examine the diagnosis and detection in the smart healthcare field. SHDD comprises two subtopics, (i) including pathology, detection, face recognition, and voice pathology detection, and (ii) smart healthcare, edge-stream, disease, medical, and diagnosis. Meanwhile, AN is one of the subject areas within the 11 subject areas that emerged in this study, which have received less attention from scholars.

4.3. Yearly distribution for each topic

Fig. 2 shows the development trend of the 11 topics on the IoT in the smart healthcare research topic. As mentioned, the topics of CPNC exhibited the largest growth from 2016 until 2018, reaching a peak in 2018. However, there was a decreasing pattern from 2018 to 2022, but the total number of publications remained over 2000 articles in 2020. The second-largest subject is BSH, which showed an increasing number of publications after 2018, with a production of over 500 from 2019 to 2021.

These trends indicate that even though there is fluctuation in the total number of publications within the period, the total remains

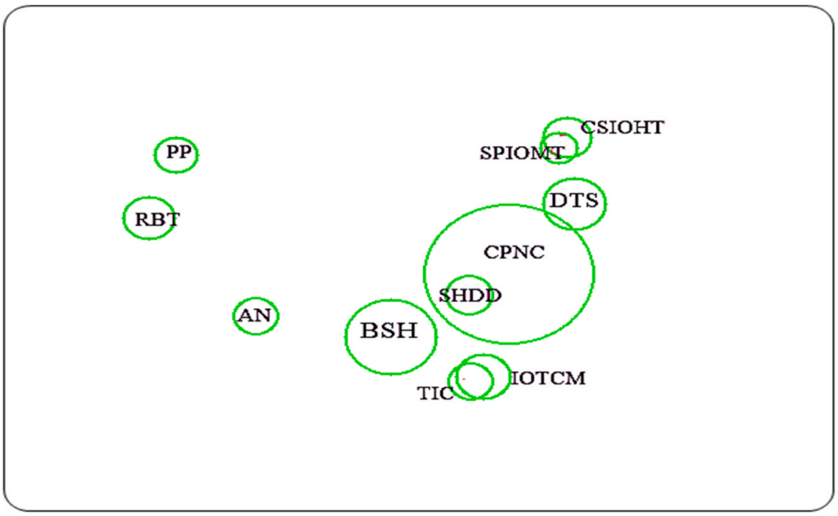

Fig. 1. Topic map rendered by multidimensional scaling from multi-stage clustering in 14 journal sources from 2016 to 2022.

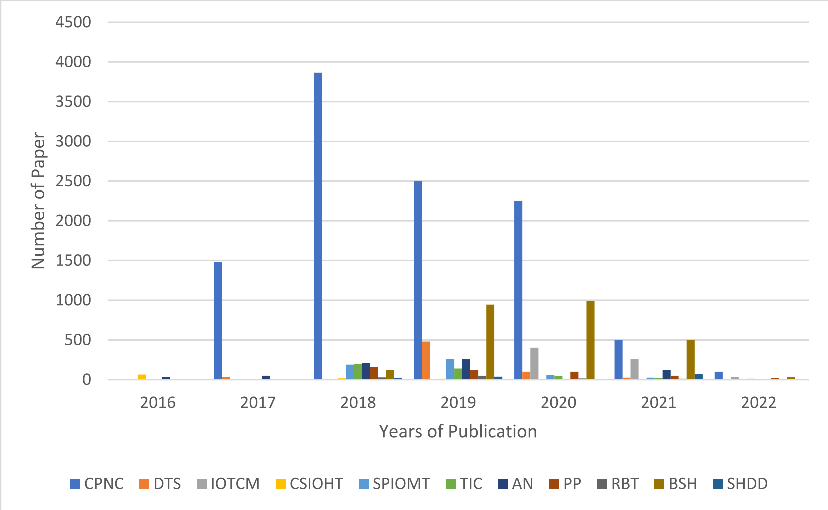

Fig. 2. The development trends of 11 topics in the IoT in the smart healthcare research from 2016 to 2022.

over 1000 articles per year. This shows that scholars still pay attention to these subject areas. On the other hand, the other subject areas within the 11 topics showed a trend of the total number of publications being less than 500 articles per year. This result suggests that scholars pay more attention to the subject areas of CPNC and BSH.

4.4. Topic distribution for each journal

Table 2 provides an overview of the topic distribution among the 11 journals, shedding light on the distinctive characteristics of each journal. The chart reveals that while some journals exclusively published content on specific subjects, others maintained a more general focus. As displayed in Table 2, only IEEE Access and IEEE Internet of things journals covered all subject areas comprehensively. In contrast, other journals concentrated on specific subsets of these subjects. For instance, IEEE Access and IEEE Internet of things journals exhibited the highest number of publications in the CPNC subject area, whereas the SHDD subject area had the fewest publications. Additionally, it's noteworthy that both IEEE Access and IEEE Internet of things journals contained a limited number of articles on the topic of BSH. Despite the relatively small total number of articles, it is evident that scholars have shown considerable interest in this particular subject area.

4.5. Geographic distribution for each topic

Table 3 displays the top 10 most prolific nations in terms of publications related to IoT in the field of smart healthcare. This information serves to illustrate the geographical distribution of articles. It is important to note that countries that contributed fewer than three articles have been excluded from this table. In total, 34 nations have made contributions to IoT in smart healthcare research across 11 publications from 2016 to 2022. Among the leading countries, China, India, and Saudi Arabia stand out as the primary contributors to IoT-related articles in smart healthcare. China takes the lead in research production, covering nine distinct topics:

Table 2
Number of articles by topics and by journals.

Journals	CPNC	DTS	IOTCM	CSIOHT	SPIOMT	TIC	AN	PP	RBT	BSH	SHDD
ACM Transactions on Internet Technology	3	0	0	0	0	0	0	0	0	0	0
Computer Communications	8	0	0	0	0	0	1	0	0	3	0
Future Generation Computer Systems-the International Journal Of Escience	11	0	2	0	4	0	3	1	0	6	0
IEEE Access	79	17	8	6	13	9	7	4	4	30	13
IEEE Internet Of Things Journal	144	16	20	8	7	10	3	10	14	36	2
IEEE Network	7	2	0	0	0	0	0	0	1	0	0
IEEE Wireless Communications	3	0	0	0	0	0	0	0	0	0	0
Internet Of Things	7	0	0	0	0	0	0	0	0	0	0
IT Professional	0	0	0	0	0	0	0	0	0	2	0
Journal Of Healthcare Engineering	1	0	0	0	0	0	0	0	0	0	0
Transactions On Emerging Telecommunications Technologies	3	0	0	0	2	0	0	0	0	0	0
Wireless Communications & Mobile Computing	11	0	0	2	0	2	0	0	0	0	0
Wireless Networks	5	0	0	0	0	0	0	0	0	0	0
Wireless Personal Communications	4	0	0	0	0	0	0	0	0	0	0

Table 3
Topics by country of authors.

Topic 1		Topic 2		Topic 3		Topic 4		Topic 5	
CPNC		DTS		IOTCM		CSIOHT		SPIOMT	
296 docs		42 docs		32 Docs		20 docs		29 docs	
China	168	China	27	China	18	China	10	India	16
USA	66	USA	5	USA	9	Pakistan	5	South Korea	11
Canada	39	Hong Kong	5	Australia	7	India	5	USA	7
UK	25	India	3	Singapore	5	Saudi Arabia	4	Pakistan	4
Australia	23	UK	3	Canada	4	USA	2	China	4
South Korea	23	Portugal	2	South Korea	3			Malaysia	3
Japan	15			Lebanon	2			Brazil	3
India	12							Portugal	3
Hong Kong	9							Saudi Arabia	3
Germany	9							Croatia	2

Topic 6		Topic 7		Topic 8		Topic 9		Topic 10		Topic 11	
TIC		AN		PP		RBT		BSH		SHDD	
China	20	China	8	China	12	China	17	China	35	Saudi Arabia	15
South Korea	4	USA	3	USA	6	USA	7	USA	17	Egypt	4
UK	3	South Korea	3	Australia	3	Canada	4	UK	16	Canada	3
Australia	3	Saudi Arabia	2	Spain	2	Singapore	3	India	9	Russia	3
USA	3					South Korea	2	South Korea	8	India	3
Taiwan	2							Saudi Arabia	7	China	2
								Norway	5		
								Canada	5		
								Pakistan	4		
								Australia	4		

CPNC, DTS, IOTCM, CSIOHT, TIC, AN, PP, RBT, and BSH. Meanwhile, India excels in the SPIOMT topic, and Saudi Arabia leads in the SHDD topic.

5. Discussion and future works

In this section, the related articles in the literature are reviewed and compared with the results obtained in this work.

In this contemporary era of communication and technological advancement, the proliferation of electronic devices, including smartphones and tablets, capable of both physical and wireless communication, has become an indispensable tool in our daily lives [42]. However, it is crucial to recognize that a significant portion of the global population lacks proper access to healthcare facilities and health monitoring services. Fortunately, modern technology, particularly the integration of small wireless solutions into the IoT, offers a promising solution. This technology enables the remote monitoring of patients, eliminating the need for physical visits to hospitals. Through the utilization of various sensors affixed to a patient's body, health data can be securely collected. Subsequently, this data can be analyzed and transmitted to a central server via different communication channels. This approach ensures that all healthcare professionals have access to and can review the collected data. They can then make informed decisions to provide remote healthcare services, bridging the gap in healthcare accessibility for those in need, regardless of their physical proximity to a hospital [43].

The gradual transition towards smart healthcare services represents a deliberate and methodical evolution. This progression is primarily due to the imperative need for continuous education and persuasion of healthcare professionals to embrace the digital age. Bridging the divide between researchers and healthcare practitioners holds the potential to address a broader spectrum of research challenges and medical conditions while fostering the adoption of more intelligent lifestyles. Electronic health, or e-health, extends an array of remote services encompassing disease prevention, diagnosis, risk assessment, patient health monitoring, educational initiatives, and treatment delivery to its users. This multifaceted approach has significantly bolstered its acceptance within society. Furthermore, the advent of cutting-edge IoT tools and technologies stands as a particularly advantageous development for e-health. The pervasive use of IoT across urban landscapes, employed for various activities, has ushered in a patient-centric and analytical approach to healthcare [44]. Diverse architectures designed for IoT and cloud have been formulated to efficiently address emergencies [45]. However, while the incorporation of IoT-backed smart healthcare solutions can enhance revenue streams and elevate the quality of life, the potential benefits are susceptible to overshadowing when security becomes compromised. Thus, safeguarding the integrity and security of sensitive information, both from the perspective of customers and developers, necessitates additional measures [46]. Ultimately, the vision and sustained success of this dynamically evolving industry hinge upon the collaborative efforts of researchers, healthcare professionals, and the wider public.

Intelligent systems play a pivotal role in granting healthcare professionals' convenient access to vital health information, concurrently optimizing costs and operational processes. This, in turn, culminates in an enhanced overall patient experience. Drawing insights from the literature, it becomes evident that robust security measures, such as access control policies and encryption, wield substantial potential in fortifying the security of healthcare systems. However, it is noteworthy that no existing standard has been identified as immediately suitable for direct implementation within a wearable, IoT-driven healthcare ecosystem.

6. Challenges and recommendations for future works

While smart healthcare promises numerous advantages, it concurrently exposes itself to heightened vulnerability. Within the realm of smart healthcare, diverse data-related challenges, encompassing factors such as data size, irregularity, and sparsity, emerge as formidable obstacles to effective data management and processing within the healthcare domain. Smart healthcare systems generate a multitude of heterogeneous data streams that often struggle to establish seamless communication at the data level. Consequently, the issue of data heterogeneity assumes paramount importance, necessitating immediate attention and resolution.

In the domain of smart healthcare, IoT devices stand as alluring targets for cybercriminals. These devices often incorporate frail security measures, and their susceptibility to compromise poses substantial risks, potentially resulting in privacy breaches and real-world safety threats. Undoubtedly, security and privacy preservation represent paramount concerns in the realm of IoT applications, with healthcare IoT being no exception. The utilization of location, personal, and contextual data is inherent to the provision of healthcare IoT services. Consequently, this engenders significant security and privacy challenges, mandating the development of innovative solution approaches to address these novel and complex issues.

A significant cause for concern revolves around the abuse of access privileges by authorized individuals. This disturbing phenomenon involves healthcare institutions inadvertently divulging confidential medical data to unauthorized parties, often stemming from a range of factors, including negligence, personal or criminal motivations, or even unlawful gains. This breach in information security extends its reach to encompass the disclosure of health records of public figures, such as celebrities and lawmakers, originating from centralized healthcare systems. Such unauthorized access not only violates regulatory norms but also leads to the exposure of documents that should remain beyond the reach of these insiders [47].

Upon an in-depth analysis of the literature, a multitude of promising avenues for future research endeavors have come to light. Among these, two areas stand out as particularly ripe for exploration, offering significant potential for advancements within the domain of IoT-based healthcare. Firstly, the realm of machine learning beckons researchers to delve deeper, presenting opportunities to revolutionize the field [48,49]. Additionally, the development of a secure, yet lightweight encryption scheme tailored for cloud storage is a pressing concern that warrants dedicated investigation. While cloud-based data storage has received substantial attention, the frontier of data processing remains largely uncharted territory. There exists a compelling need to advance research in this direction. Specifically, the refinement and expansion of cloud-based algorithms capable of processing raw data emanating from intricate sensors and extracting meaningful insights pertaining to an individual's health represent a crucial avenue for sustained inquiry and innovation.

Recognizing the imperative for IoT interoperability and international collaboration in the development of digital health infrastructure emerges as a pressing need. This challenge, compounded by the absence of robust IT infrastructure, can be attributed to a twofold issue: a scarcity of IT expertise and the necessity for global cooperation in the secure sharing of confidential medical data. Such collaboration is pivotal in advancing remote telemedicine services and ensuring the delivery of top-tier medical care. Enter shibboleth, a distributed identification key that plays a pivotal role in this context. This mechanism facilitates user authentication within and across organizational systems. Traditionally, shibboleth mandates that a user verifies their identity to an ID provider, subsequently triggering a request to access a service hosted by a service provider. Through this distributed approach, Shibboleth empowers digital health organizations with a unified single sign-on capability, exemplifying its utility in the context of digital healthcare systems.

The progression of next-generation wireless networks heralds significant potential for the realm of smart healthcare. Thanks to the emergence of 5G and the even more advanced beyond 5 G networks, the global healthcare infrastructure can now be accessed with unprecedented speed and efficiency from virtually any corner of the world. Moreover, these advancements empower the facilitation of federated deep learning and edge-based computing, making these technologies more accessible and potent than ever before [50].

7. Conclusion

This study introduces a novel approach to subject analysis, departing from the conventional manual methods employed in IoT research. It achieves this by integrating blockchain, multi-stage clustering, and content analysis techniques. Over seven years, we identified eleven subject categories across 14 journals. Our utilization of blockchain enabled us to group papers with similar epistemological foundations, shedding light on the knowledge creation process within IoT-related smart healthcare research. For instance, it revealed that researchers historically paid less attention to the newly emerging thematic cluster concerning certificateless signcryption within the IoHT and patient privacy.

Additionally, the most frequently referenced articles within each field can be considered essential readings. These articles serve as valuable resources for graduate students, lay scholars, and practitioners seeking foundational knowledge or exploring potential areas for future research. Furthermore, these findings offer valuable insights into the journals most likely to publish specific articles, aiding authors in selecting the most suitable publications for their work. This methodology holds promise for future development and periodic use in tracking the evolution of IoT in smart healthcare research.

Approval of the submission

All authors have approved the paper's publication.

Data availability statement

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Hai Ziwei: Conceptualization. **Zhang Dongni:** Conceptualization. **Zhang Man:** Methodology, Data curation. **Du Yixin:** Methodology, Data curation. **Zheng Shuanghui:** Software, Investigation, Formal analysis. **Yang Chao:** Writing – original draft, Resources, Project administration. **Cai Chunfeng:** Writing – review & editing, Visualization, Validation, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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