electronics

Article

A Bibliometrics Analysis of Medical Internet of Things for Modern Healthcare

Hoang-Sy Nguyen [1], Huynh-Cong Danh [2,*], Quoc-Phu Ma [3], Jakub Mesicek [3], Jiri Hajnys [3], Marek Pagac [3] and Jana Petru [3]

[1] Becamex Business School, Eastern International University, Thu Dau Mot City 75100, Binh Duong Province, Vietnam; sy.nguyen@eiu.edu.vn
[2] Faculty of Economics, Thu Dau Mot University, Thu Dau Mot City 75100, Binh Duong Province, Vietnam
[3] Department of Machining, Assembly and Engineering Metrology, Faculty of Mechanical Engineering, VSB-Technical University of Ostrava, 70833 Ostrava, Czech Republic; marek.pagac@vsb.cz (M.P.); jana.petru@vsb.cz (J.P.)
* Correspondence: danhhc@tdmu.edu.vn

Abstract: The integration of the Internet of Things (IoT) in healthcare has been a popular topic in recent years. This article provides a comprehensive review of the medical IoT for healthcare, emphasizing the state of the art, the enabling technologies to adopt virtuality and reality interaction, and human-centered communication for healthcare (the Metaverse, Extended Reality (XR), blockchain, Artificial Intelligence (AI), robotics). In particular, we assess the number of scientific articles and patents within the period 2015–2022. We then use the two-stage process following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) and screening techniques. From that, the relations among the published papers can be visualized. This study examines the insights by evaluating the weights and connections of the nodes in the bibliometric networks. The reviewed papers showcase the rapid growth of IoT-related studies and intellectual property developments, reflecting the burgeoning interest and investment in this domain. As this paper delves into the network of interconnections between these works, it fosters a deeper understanding of the current state of IoT applications in healthcare and uncovers potential research gaps and areas for future exploration. This paper also provides a brief view of the role of IoT in healthcare research and application in combination with emerging technologies such as AI, blockchain, the IoT-enabled Metaverse, robotics, and cloud computing. The article can serve as a guideline and inspiration for both researchers and practitioners in the smart health service sector.

Keywords: Internet of Things; healthcare; bibliometrics analysis; visual analysis

Citation: Nguyen, H.-S.; Danh, H.-C.; Ma, Q.-P.; Mesicek, J.; Hajnys, J.; Pagac, M.; Petru, J. A Bibliometrics Analysis of Medical Internet of Things for Modern Healthcare. *Electronics* **2023**, *12*, 4586. https://doi.org/10.3390/electronics12224586

Academic Editor: Juan M. Corchado

Received: 29 July 2023
Revised: 30 October 2023
Accepted: 7 November 2023
Published: 10 November 2023

1. Introduction

The Internet of Things (IoT) has recently emerged as a state-of-the-art technology in healthcare systems. IoT stands for a network of smart objects or devices that are interconnected via the Internet, opening up a new era for practical applications or services that it is embedded with [1]. In the existing literature, some define IoT with more focus on the connection type (via Wireless Sensor Network (WSN), Radio Frequency Identification (RFI)), while others focus on the object types (for particular applications and services) in particular scenarios (security, waste management, logistics, healthcare, etc.). Owing to the extensive capability to detect signals and communicate them, IoT devices have been widely adapted for human detection, early diagnosis, and health monitoring in distance, which is exclusively necessary for elderly care [2]. These advantages, indeed, have significantly improved the healthcare system by reducing hospitalization costs and maintaining sanity while ensuring that timely care can be carried out for critical cases. In the context of smart cities, a healthcare system supported by IoT has the potential to positively affect the whole value chain [3].

Applications of IoT in healthcare can be found in wearables (watches, clothes, gloves, etc.) containing sensors that constantly collect patients' data and then send them via wire or wireless connection to monitoring devices (smartphones, tablets, computers, etc.). The data extracted from those devices can later be used by their doctors for following health consultation or treatment [4]. Since the early days, whether or not IoT is necessary for healthcare is necessary and cost-effective was debatable [5]. The authors in [6] later reported that IoT can automize clinical trials for patients, which is significantly valuable for them. By conducting a market study including supply chain analysis, motivation for innovation, and other quantitative measures, the authors in [7] confirmed that IoT has shaken many aspects of the healthcare systems.

A typical workflow for IoT in healthcare is as follows. First, data are collected either through sensors or provided by doctors and nurses. Subsequently, this collected data are processed using diagnostic models, increasingly employing Artificial Intelligence (AI)-based algorithms in recent times. Based on the output of these models, IoT devices can determine if immediate action is required for the patients or if the data should be stored and forwarded. This capability allows doctors to remotely monitor the patient's condition and make well-informed decisions with the assistance of IoT devices. The emergence of IoT in modern healthcare is due to its ability to offer the real-time, simultaneous monitoring and reporting of a patient's condition through robust machine-to-machine connectivity while maintaining affordability. In terms of data collection and subsequent analysis, IoT devices can operate in real time, enabling them to make decisions based on these data and thereby reducing the need to store and process raw data. By storing data in the cloud, IoT devices facilitate remote monitoring and enable more efficient diagnostic and medical treatment processes [8].

The existing studies pay attention only to particular technologies or applications. For new researchers, keeping track of the trends in the field is hard because of the number of existing works, including patents and scientific papers. Therefore, we employ herein bibliometrics study to investigate the status of IoT in healthcare both from the practical and academic views. Bibliometrics refers to a quantitative approach that can be used to analyze a set of scientific data (patents, clinical trials, grants, publications, etc.). One of the results is to show the relations between the published works so that the current status and the trends can be captured. Aside from the traditional quantitative tools, semantic technologies, and machine learning were also employed in monitoring and forecasting the knowledge flow between the industry and the academy [9].

Similar to the previous literature assessments, bibliometric studies include a defined description of rigorous methodology [10–12]. Bibliometrics is a branch of science that uses statistical and mathematical approaches to assess scientific activity [13]. Through performance analysis with authors, nations, and institutions, these studies make it possible to examine the intellectual structure of the research area. Furthermore, bibliometric mapping (science maps) allows for the observation of structural links and interrelationships across disciplines and research sectors [11,12]. Therefore, using bibliometric analysis to understand the structure of a knowledge base in a certain topic is beneficial. This paper's findings may be used as a reference for anyone interested in advancing and deploying technology for sustainable healthcare research. It can help fill a gap in the literature review. The approach used in this study to identify critical research topics is unique, and it may also be used in other academic and technical sectors.

The aim of this paper is to analyze the existing patents and literature in the field of IoT in the healthcare industry to find out whether or not the academic knowledge aligns with the practical patterns during the investigated year range. The paper covers a broad range of topics to provide the most general view into the field. The research questions and the motivations behind them are presented in Table 1 regarding the healthcare IoT.

Table 1. Research questions and motivations.

Research Question	Motivation
(1) Does there exist any alignment between the academia (number of scientific publications) and the industry (number of patents)?	The industry could be the main driver for the development of IoT in healthcare due to its active role in commercially oriented R&D activities, which results in funding for academia.
(2) What are the most popular sources of literature and authors?	It is important to identify the primary sources for publications, in terms of scientific publications and their authors, for reliable and resourceful references.
(3) What is the current status and the potential trend?	The connection of the currently available publications would suggest what is the current status of the field and the research gap, potentially providing insightful information for trend prediction.

The motivation for the research questions stems from the fact that IoT has been emerging and redefining the way we interact with our environment [14], where data collection and sharing are possible in real-time between devices that are linked to the internet [15]. The number of linked devices has been massively growing and can reach 75 billion devices by the year 2025 [16,17]. Billions of these devices will significantly transform modern healthcare with improved patient care, early disease detection, and enhanced operational efficiency. This can be achieved only through enhanced collaboration between the industry and scientists. Considering this, it is of utmost importance to study their collaboration, the most dependable sources for knowledge reference, and potential trends.

In other words, this research elucidates a systematic approach for formulating the research questions, identifying an appropriate database, ascertaining pertinent search terms, selecting suitable analytical software, extracting relevant data, and conducting an in-depth analysis of the findings. The procedural steps are visually depicted in Figure 1 and elaborated upon comprehensively in the subsequent sections.

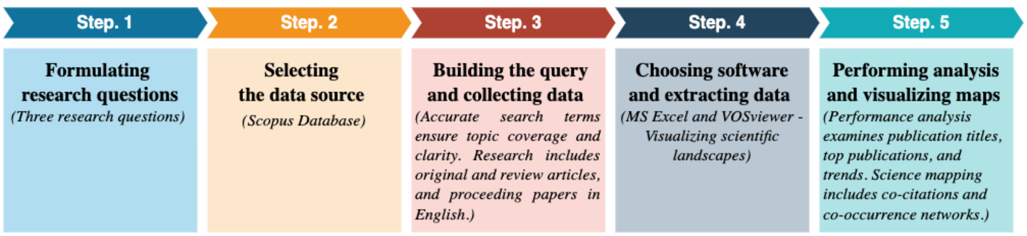


Figure 1. Method processing.

To achieve these goals, we collected, studied, and visualized the number of scientific publications and patents over the years. The top journals in which the papers were published, the relation between the authors and the keywords in the field are also well reported.

2. Materials and Methods

2.1. Data Collection

The study focuses on English documents in the Scopus database that were published between 2015 and 2022. This range was chosen for the investigation because 2014 was found to be the milestone for the increased interest in advancing healthcare research with IoT [14]. Scopus was chosen for this initial study because of its wide journal index. To ensure that the analyzed publications are widely reachable by the research community, only the ones written in English were collected. In the Scopus database, the searched terms "Internet of Things" and "Health" were used. The query returned 577 articles and 250 patents. The results were then exported to a comma-separated values (csv) file format and analyzed. Regarding the method for the analysis, we used the two-stage process following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [18] and screening process reported in [19,20].

Figure 2 illustrates in detail the PRISMA 2020 flow diagram for the research design. From an initial search result of 23,145 publications in the Scopus database, 6448 publications remained after the first exclusion round. After this round, all the papers that are repeated, in proceedings, preprints, or other incompleted formats, and written in another language other than English are excluded. The remaining were further filtered to include only those exclusively related to the field of Medicine, resulting in a final set of 557 publications.

The examination of healthcare information systems and the role of technology in healthcare renovation need systems for comprehending how change occurs within this complex setting. Thus, we present the approaches and tools we used to collect and clean up our data and analysis of literature on technology for sustainable healthcare. VOSviewer [21] was then used to visualize the maps of authors, the top journals that they chose to submit their works, and the research keywords. From the initial two keywords ("Internet of Things" and "Health"), others that are associated with them can be found, as illustrated in Table 2. Noticeably, two or more keywords with the same meaning were merged, such as "IoTs" and "Internet of Things", "human" and "humans", "health" and "healthcare", etc.

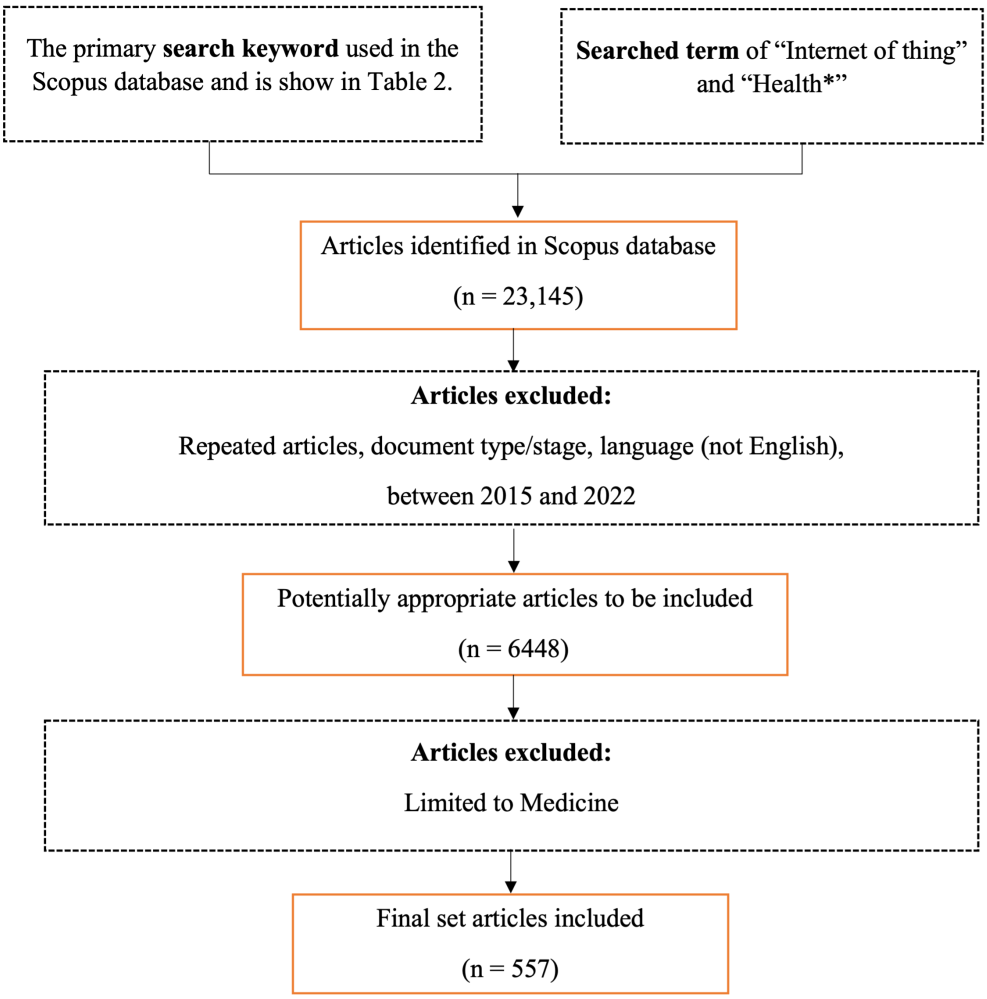


Figure 2. Flowchart of the study with PRISMA.

Table 2. Summary of search keywords.

Keywords
"Human*", "Internet of things", "Medical information standards*", "Digital health *", "Mobile health *", "Virtual reality in health", "Augmented reality in health *", "Medical image analysis", "Medical devices", "Health monitoring", "Telemedicine *", "Sensors", "Virtual reality in health *", "Augmented reality in health *", "Artificial intelligence *", "Clinical decision support ", "Decision support systems *", "Healthcare *", "Hospital quality *", "Hospital referral *", "Hospital collaboration *", "Patient referral problem *", "Hospital *", "Interhospital *", "Hospital collaboration *", "Magnetic resonance imaging *", "Clinical decision support *", "Healthcare systems *", "Patient referral network *", "Healthcare coordination *", "Integrated healthcare *", "Medical services*", "Primary health care *", "Specialties *", "Medical clinical practice *", "Quality of healthcare*", "General practice *", "Intervention *", "Primary care *", "Ambulatory care *", "Health communication *", "Diagnosis *", "Health centres *", "Healthcare innovation *", "General medical *", "Patient-centered care *", "Electronic referral *", "Patient-referring mechanism *".

2.2. Research Methods and Tools

This paper primarily employs the bibliometrics method. It is a quantitative approach that applies statistics to analyze the patterns of documents in a particular field to transform data into knowledge [22]. There are primarily two consecutive steps in bibliometrics study, i.e., performance analysis and science mapping [23]. The former evaluates the impact of knowledge producers (researchers, organizations, countries) and their activities based on bibliographic data, while the latter depicts the dynamic and evolution of the knowledge structure as well as the trends. This is achieved by visually representing the connections between different authors in various fields through physical proximity and relative positioning [24]. The two most popular analytical techniques are document co-citation analysis and co-word analysis. A document co-citation investigates the research field and maps its knowledge structure by studying pairs of documents that are cited together. Additionally, co-word analysis analyzes the content by examining the shared term set among documents from which related documents can be mapped based on how the key inputs interact. Results from co-citation analysis or co-word analysis help us to identify current research focal points, analyze how the knowledge structure evolves, and identify its trends [25,26].

The VOSviewer software version 1.6.20 enables the extraction of information regarding authors, countries, journals, and other relevant data via bibliometrics www.vosviewer.com. It facilitates the visualization of citation and co-occurrence networks. The software shows its strength in performing information extraction, network density, and visualization of clusters. Herein, we utilize the VOSviewer software to extract information about authors and their affiliations and journals in which the papers were published. Moreover, we employ the software to analyze the core groups of authors, published journals, and the collaborative network of organizations based on affiliations.

3. Results

3.1. Annual Production of Patent and Publications

So far, IoT has gained significant attention and growth within the healthcare industry [27]. Figure 3 depicts the distribution of publications over an eight-year period between 2015 and 2022. Initially, in 2015, there was a modest start with only three publications recorded in 2015 alone, indicating that research on applications of IoT in healthcare is relatively new. Until 2016, the number of studies remained low; however, there was a significant increase in research output after 2017. Since then, we can observe an upward trend in research activity in this field, indicating that IoT in healthcare will remain a prominent area for research attempts in the future. Subsequently, we examined the involvement of researchers in research about smart healthcare based on IoT. Within the same year period, we analyze the number of research outputs in terms of scientific studies to identify the trend in annual author contributions.

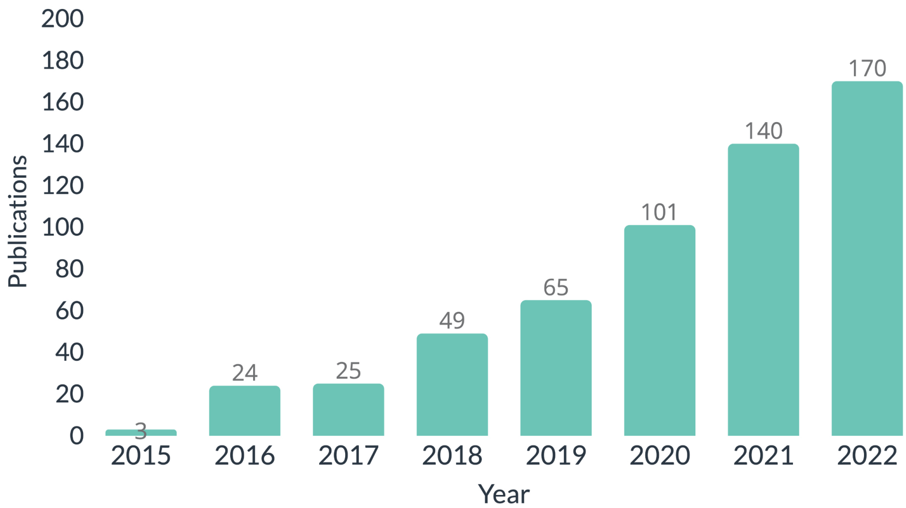
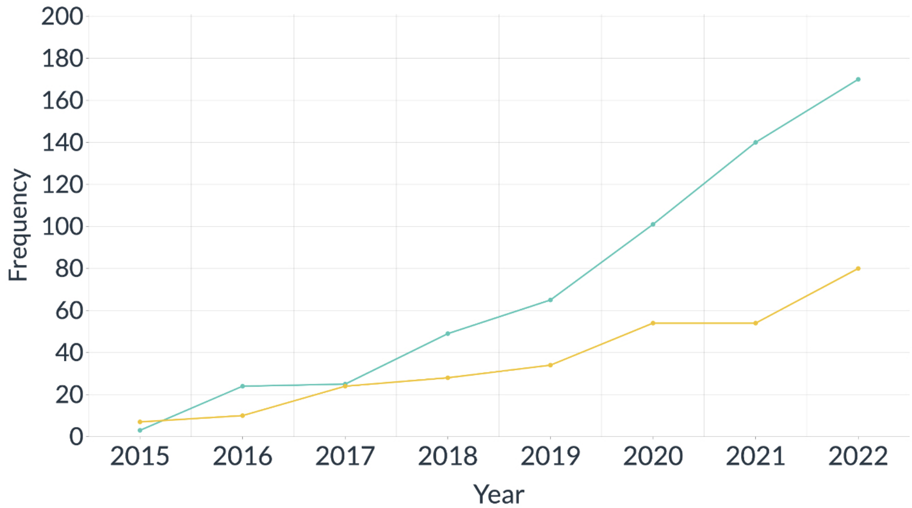


Figure 3. Distribution of publications over the years from 2015 to 2022.

Figure 4 presents a combined view of the yearly scientific products (scientific articles and patents) associated with the IoT in healthcare within the past eight years. Starting from 2015, the number of articles steadily increased to reach a peak of 170 articles in 2022. This substantial rise in publications indicates a growing intensity in academic production, which is likely attributed to the companies' interests in innovating IoT applications specifically for the healthcare sector. Additionally, we observe as well a significant increase in the annual patent number discussing the IoT applications in healthcare within the same year period. In the initial two-year period (2015–2017), 41 patents were generated (25% of the total), whereas the second period (2018–2022) witnessed a considerable surge in patent filings with 250 patents.



Articles	3	24	25	49	65	101	140	170
Patents	7	10	24	28	34	54	54	80

Figure 4. Annual articles and patents production by years.

3.2. Journals Distribution Publications

The publication distribution analysis reveals that there are 577 publications spread across 199 journals. The top ten journals and their corresponding number of publications over the eight-year period are listed in Table 3. We can observe that *The Journal of Healthcare Engineering* ranks first with 60 publications. This journal covers topics in Medicine, Surgery, Health Informatics, and Biotechnology. In addition, as per Scimago Journal & Country

Rank (SJR), the journal's h-index is 37. Ranking second in the list is *The International Journal of Environmental Research and Public Health*, whose focuses are on public health, toxicology and mutagenesis, pollution, environmental, and occupational health. It has an h-index of 138 as reported by SJR. *The Journal of Medical Systems* secures the third place and covers computer science, health professions, medicine, information systems, health informatics, and information management with an h-index of 89. Other journals in the list have similar amounts of publications.

Table 3. Ranking of journals by the number of publications.

No	Publisher	Publication Number
1	*Journal of Healthcare Engineering*	60
2	*International Journal of Environmental Research and Public Health*	35
3	*Journal of Medical Systems*	33
4	*IEEE Journal of Biomedical and Health Informatics*	21
5	*Jmir Mhealth And Uhealth*	16
6	*Journal of Medical Internet Research*	15
7	*Technology and Health Care*	14
8	*Frontiers in Public Health*	13
9	*Smart Health*	13
10	*Indian Journal of Public Health Research and Development*	10

3.3. Knowledge Base Analysis

In general, it worth introducing the concept of networks that are reported in this paper, i.e., the co-citation network and the co-occurence network. A network is characterized by nodes and connections. The size and color of the node indicate, respectively, the importance of the node in the network and the classification of the node. Nodes are connected by links whose thickness represents the connection strength between two nodes. Based on the distribution and connection of nodes in a network, it is possible for the analyst to visualize, cluster, interpret, and report the overview of the field.

A co-citation network is a knowledge network that records instances when a scientific document cites two other documents simultaneously [28]. In other words, co-citation analysis studies the relationship between documents based on their frequency of citation by others. When a document, a journal, or a group of researchers is repeatedly cited by the research community, it implies the recognition of the community to the cited. This forms the so-called scientific paradigm that the co-citation network visualizes [29]. Herein, the preprocessed data are imported into VosViewer, where the co-citation relationships are analyzed, resulting in a co-citation network depicted in Figure 5. In the network, a node is a commonly cited document with the size indicating its citation frequency. Nodes with the same colors are documents published in the same year. The connections between nodes show the co-citation relationships whose thickness reflects the strength of the connection. Such a co-citation network effectively demonstrates the knowledge base within the field of smart healthcare research associated with IoT.

The article by Vaishya R. entitled "Artificial Intelligence (AI) applications for COVID-19 pandemic" published in *Diabetes & Metabolic Syndrome: Clinical Research & Reviews* in 2020 has the highest citation number of 608 citations [30]. This article is cited 1055 times according to Google Scholar. Following, in [31], the author Haghi M. (2017) has 408 citations, Singh R.P. (2020) has 345 citations [32], Yang Z. (2016) has 298 citations [33], and Allam Z. (2020) has 219 citations [34]. All of these articles are connected to Vaishya R. [30], showing that there is a strong correlation between the most cited works in the field and the similarity in their topics, i.e., IoT and its applications. This indicates that research on IoT in healthcare has reached its initial maturity stage and is being standardized by other branches of research.

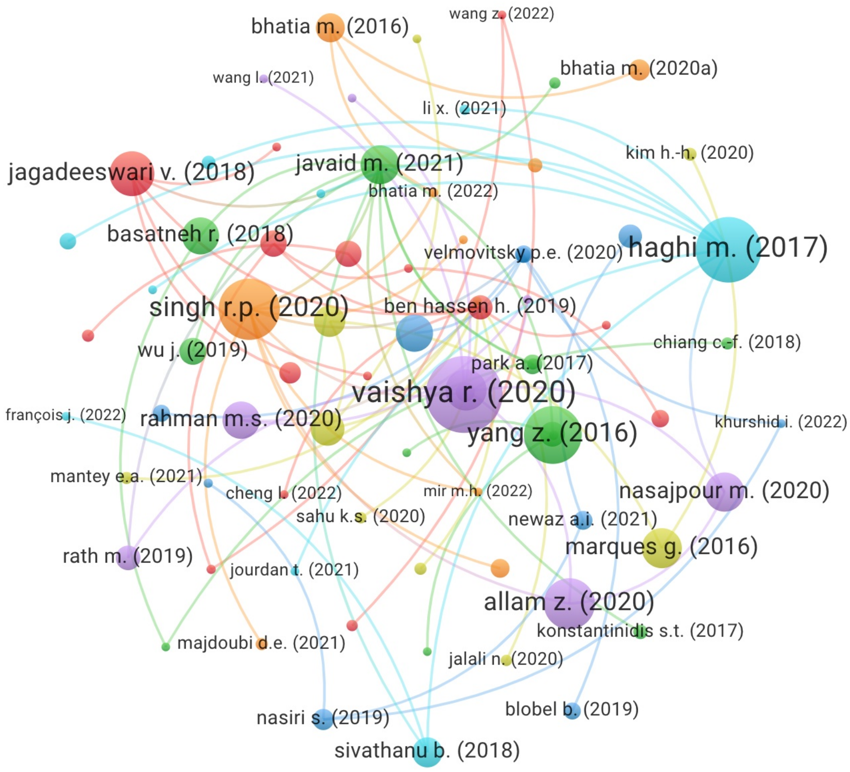


Figure 5. Articles in the co-citation network.

The co-word network is as well a knowledge network that represents scientific knowledge through the co-occurrences of keywords. In general, keywords provide the first view and concisely the core essence of a scientific article. They are to-go means for search tools to identify the research landscape within the field of medical IoT. Herein, keywords are extracted from 577 documents in association with medical research. Frequency and co-occurrence studies are conducted to investigate the current structural foundations of the knowledge base and research hotspots regarding smart healthcare based on IoT. From the visualized network, the future direction can be predicted. In Figure 6, we can see that IoT emerges as a core focus. The research in the smart healthcare domain is primarily based on the IoT and encompasses multiple themes. Each node in the network is another keyword whose size is proportional to the frequency of its co-occurrence. The thickness of the connections between a pair of nodes indicates the strength of co-occurrence between them. Colors are used to classify the years the keywords co-occurred.

Medical IoT is anticipated to continue being the central focus in this field. The emphasis will be on integrating IoT in smart healthcare systems to address security and privacy concerns to ensure users' confidence. In addition, IoT often intersects with other state-of-the-art technologies such as big data, cloud computing, and Artificial Intelligence (AI). Therefore, it is expected that these keywords will frequently appear together with IoT in future studies within this field. This combination facilitates the development of the smart home and smart cities definitions, in which IoT technology is used to connect various devices within households for real-time communication and response, making the living space more convenient and safe. One promising research direction in this field is the continuous and accurate monitoring of patients' health by measuring various body parameters to provide timely feedback to remote doctors. Currently, only a limited number of studies explore the application of IoT technology for treating specific diseases, which can be one of the future research trends to be explored.

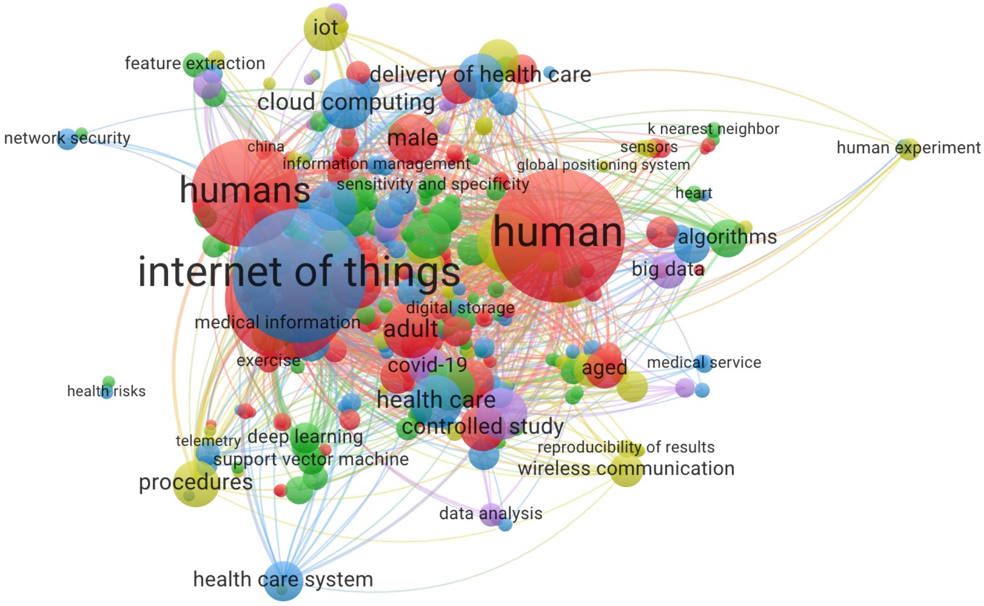


Figure 6. Keywords in the co-occurrence network.

4. Discussion

Smart healthcare systems have emerged as popular research areas, offering potential benefits in various aspects. Furthermore, when examining the knowledge base in this field, it becomes apparent that the literature forms a closely interconnected network revolving around the medical IoT. This suggests that a solid foundation of knowledge has been established, which can significantly contribute to future research and application endeavors.

For instance, a smart system can serve as a household health consultant by providing features such as alerts for the elderly and children, notifying family members, and providing location information in case of an emergency. Additionally, the system can automatically control the air purifier based on real-time air conditions, eliminating the need for manual setting. Additionally, a crucial aspect of constructing smart cities involves the development of a smart healthcare system. As part of this effort, a big data platform storing medical information can be established within the smart city infrastructure. This platform can facilitate data sharing and collaboration among healthcare organizations.

Furthermore, the smart healthcare system can as well rely on a cloud platform to establish a centralized big data center to store the medical information of its citizens, enabling the promotion of integrated healthcare services and the implementation of a tiered diagnosis and treatment approach. Additionally, the smart system can establish electronic health records (EHRs) for its residents, enabling seamless connectivity among healthcare facilities throughout the smart life. This connectivity will facilitate remote registration, electronic payment systems, online telemedicine services, and advanced systems for graphic and physical examination diagnostics. The comprehensive implementation of these measures will greatly enhance the quality and accessibility of medical and health services.

However, it is important to acknowledge that the AI-integrated Metaverse exposes patients to significant risks concerning their privacy, ethics, and the potential for medical errors that could mislead doctors and result in incorrect treatment. Nonetheless, this integration offers valuable insights while being able to interact with healthcare data centers, which is highly beneficial for both patients and doctors. Furthermore, 3D modeling in the Metaverse can bring numerous benefits, as it enables the creation of interactive anatomical representations using high-quality imaging. This allows patients to visually try out the medical devices to select the appropriate ones for their needs [35]. Furthermore, 3D models built in the Metaverse can empower doctors to gain a deeper knowledge of a patient's illness, leading to improved care and more precise treatments [36]. Additionally, medical researchers can leverage the Metaverse to create virtual (artificial) organs and assess their behaviors with simulation.

Blockchain technology, which is a distributed and duplicated digital database of transactions across a network, has the potential to boost healthcare services within the Metaverse, making them more secure and efficient [37–39]. As a distributed ledger technology (DLT), blockchain offers a secure platform for storing sensitive data and patient records. Moreover, blockchain-based systems have the potential to automate payments between healthcare service providers and users without the need for intermediaries or manual operation. Additionally, decentralized identity protocols implemented on blockchains like Ethereum can provide access to medical information to authorized persons while granting better health data control to the patients [40].

Another emerging research focus is on the implementation of telesurgical schemes in a virtual hospital setup. It has the potential to profoundly impact the healthcare ecosystem, enhancing operational capabilities, service accessibility, and the overall experience for both patients and clinicians. These can be achieved with AI, Extended Reality (XR), and cloud computing [41]. Additionally, the authors in [42] investigated an extensive integration of the Metaverse with the blockchain, AI, IoT, and other related technologies. The study critically assessed the feasibility of these technologies in facilitating various healthcare applications in the Metaverse. Furthermore, the potential of medical IoT in the Metaverse was explored in [43] with a focus on the utilization of XR (augmented reality (AR), virtual reality (VR)). In the study, doctors were interviewed for their insights on the feasibility of implementing the Metaverse for improving the process, perception, and transmission in the Medical IoT domain. The integration of AR/VR glasses with holography, emulation, and interconnection would bring greater benefits to the interaction between doctors and patients or doctors and medical information. Moreover, [44] provided a concise overview of the Metaverse, outlining the potential revolution that it would bring to modern healthcare while addressing implementation challenges such as high costs, privacy concerns, ethical considerations, and agreement issues faced by healthcare administrations and organizations [45,46]. These recent studies have significantly contributed to refined visualizations, understanding, and practical applications of novel techniques, as summarized in Table 4. The future of healthcare research lies in addressing the evolving needs and challenges of the healthcare sector through innovative and transformative approaches. The table outlines potential future research directions, including technology-driven advancements, patient-centric care, healthcare policy and systems, and interdisciplinary collaborations. By prioritizing research in these areas, researchers and stakeholders can contribute to shaping the future of healthcare, driving positive change, and improving healthcare outcomes for individuals and communities [47–50].

Furthermore, transformative technologies such as AI, IoT, blockchain, AR/VR, and robotics have the potential to revolutionize healthcare delivery, improve patient care, and transform decision-making processes. These technologies present opportunities to enhance efficiency, accuracy, and accessibility in healthcare settings. In previous studies [51,52], the IoT has demonstrated its ability to connect healthcare devices, wearables, and sensors, enabling real-time monitoring, remote patient management, and seamless data exchange. IoT-enabled healthcare systems enable continuous patient monitoring, early detection of abnormalities, and proactive interventions. Integrating IoT devices and platforms with EHRs and data analytics enhances the coordination of healthcare services and the engagement of patients as well as the health management system of the population in general.

Blockchain technology, as highlighted in [53], can facilitate consent management, clinical trials, supply chain management, and precision medicine initiatives, promoting trust, security, and privacy in healthcare data transactions. AR and VR technologies have also gained traction in healthcare for purposes such as training, surgical planning, patient education, and telemedicine. These immersive technologies provide healthcare professionals with visualizations of complex medical scenarios, simulate surgeries, and enhance medical education. They offer novel avenues for remote collaboration, virtual consultations, and therapeutic interventions, ultimately improving patient outcomes and expanding access to specialized care [42,44]. Nevertheless, challenges related to data privacy, ethical considerations, standardization, and implementation barriers must be addressed to fully capitalize on the benefits of these enabling technologies. Continuous research, collaboration, and policy initiatives are essential to navigate the evolving healthcare landscape and maximize the potential of these technologies [54,55]. Finally, projects and real-time case studies play a crucial role in providing valuable insights into the practical application of research findings in healthcare. Selected projects and case studies have showcased the potential of digital health interventions, telemedicine, precision medicine, health informatics, and innovative healthcare delivery models [56–59]. By adopting evidence-based practices derived from these initiatives, healthcare stakeholders can enhance patient care, optimize resource allocation, and drive continuous improvement in healthcare delivery.

Table 4. Summary of the future of revolutionized healthcare.

The Potential Future Research Directions in Healthcare	Key Enabling Technologies and Their Impact on Healthcare	The Practical Application of Research Findings in Healthcare
[42,44–50]	[42,44,51–53]	[56–59]

The research questions have been answered as follows.

1. There is a direct relation between the number of scientific publications and the patents. This serves as evidence of the close partnership between academic research and the industry. Academic research plays a critical role in providing evidence, critical analysis, and guidance to translate the industry's commercially motivated IoT healthcare advances into improved care delivery and health outcomes. Ongoing collaborations between academia and industry will be important to ensure IoT healthcare innovations are rigorously developed, evaluated, and responsibly implemented to maximize benefits for patients and health systems. As a result, industry activity creates new research questions and opportunities for academia, while academic research provides the evidence base and framework for the effective real-world application of industry innovations. This interdependence ultimately benefits the end-user. Therefore, more work is needed to strengthen collaboration and alignment between commercial and scientific efforts in this emerging field.
2. The ten most popular publishers for publications and the map of authors who have the most influence in the field are presented. Focusing on literature from the top publishers and citations of influential authors based on bibliometrics can help identify reliable and informative sources on IoT in healthcare. The list highlights major technology publishers in the Scopus database as well as key medical journals like *The Journal Of Healthcare Engineering*. The peer-reviewed publications in these journals have been filtered for quality. The following citations and references from high-impact articles can also uncover influential works. Given the fast growth of this research field, bibliometrics tracking can pinpoint emerging seminal contributions.
3. Bibliometric analysis of current publications on the IoT in healthcare reveals fast-paced, technically focused research interest, highlighting need for more clinical collaboration, evaluations, and governance to successfully translate academic IoT innovations into patient and healthcare benefits. The research gaps and potential trends are presented in detail in the next section.

5. Challenges and Trends

Research is rapidly accelerating with a sharp growth in publications over the past years. This suggests increasing academic interest as the field gradually becomes mature. Active research spans applications like remote monitoring, chronic disease management, elderly care, hospital workflows, medical devices, etc. Technical aspects cover security, interoperability, data analytics, wearables, and integration. Most contributions come from engineering and computer science fields with growing involvement from healthcare academics. This implies a need for more clinical collaboration to popularize the usage of medical IoT devices.

Additionally, studies mainly focus on proposing new systems or algorithms, while evaluations of real-world implementations and outcomes are still limited. This is also evident from the modest number of patents. From the bibliometric study, the challenges of implementing medical IoT devices in routine care and public health can be identified, which can be seen as research gaps and opportunities for improvement. The challenges are outlined below.

- Adoption: Operating IoT devices requires proper training and an adaptive mindset to new technologies. The resistance to changes could hinder healthcare organizations from implementing IoT solutions effectively. Educating (potential) users is essential for the providers of IoT devices.
- Privacy and Security: IoT devices continuously collect personal and sensitive data from patients, raising a paramount concern for cybersecurity. To safeguard such information, besides staying adhered to regulations, for example, the HIPAA (Health Insurance Portability and Accountability Act), other security measures such as blockchain can be considered.
- Interoperability and Integratability: Because IoT devices for medical purposes are from a variety of different suppliers, ensuring seamless and thorough communication among them is challenging. In view of this, data silos are a big concern for scalable and effective patient care. Integrating IoT devices into the current healthcare system, for example, EHRs, would be complex.
- Regulation and Standardization: Healthcare and emerging IoT devices are two subjects of stringent regulation. Staying up to date with the regulatory requirements from the appropriate responsible authority could be demanding in terms of time and cost. This is exacerbated by the lack of comprehensive industrial standards for IoT solutions.
- Accuracy and Reliability: IoT devices are expected to be resilient in collecting and processing a continuous flow of data when ensuring that the data are accurate. Inaccurate or misleading data can lead to inappropriate treatments or even misdiagnoses.
- Data Storage and Usage: The huge amount of data generated by IoT devices requires adequate infrastructure, mostly clouds, to store, manage, and analyze. An appropriate strategy for data management is required to avoid being data-overwhelmed. Additionally, accompanying the regulations, ethical matters regarding potential surveillance, responsible collecting and usage of patient data are also important.
- Power Supply: Since IoT devices are mainly powered with batteries and need to be operated nonstop, new solutions for consistent power supplies can contribute highly to the field.
- Costs: While IoT devices for end-users can be affordable, companies that offer the solutions have to consider the cost of the above-mentioned requirements to allocate their resources effectively for optimal Return of Interest (ROI).
- Environmental Impact: Sustainability should be taken into account in the design and product lifecycle assessment of IoT devices, as manufacturing and disposing of them can have a negative environmental impact.

To tackle these challenges, it is essential for healthcare providers, technology innovators, regulatory bodies, and patients to work together to establish a secure, interconnected, and morally sound IoT ecosystem within the medical domain. Nonetheless, it is worth mentioning the role of enabling technologies such as the Metaverse, XR, blockchain, AI, and robotics in R&D activities for the improvement of IoT solutions. The listed challenges can be the potential research opportunities for both technical and non-technical fields.

6. Conclusions

From the findings of the study, it can be observed that there are not many studies about the applications of IoT in healthcare. Although the topic was raised in 2017, the research into it only started to surge in 2019, coinciding with the appearance of the COVID-19 pandemic. This is obvious because of the need to maintain the healthcare system with cost efficiency in a non-contact manner. The networks of co-citation show that even though the field has been growing for years, the number of publications in the field is still low, and research works are not widespread. Owing to the bibliometrics study, we can understand the growth of the research trend and discover the key problems in the field, from which we can predict and direct future works more appropriately. It is predicted that the upcoming years will witness the significant growth of IoT together with cloud computing, big data, and machine learning applications in healthcare, forming a solid knowledge foundation for smart healthcare systems in practice.

Future studies will focus on several areas which are the limitations of this study. Firstly, there will be an investigation into how IoT and other state-of-the-art technologies can contribute to improving healthcare accessibility. Secondly, we can evaluate the objects and whether the published results are reproducible. In addition to this, examining how authors in the field and industry are related can help us assess any potential biases or influences. Thirdly, it is possible to utilize a broader range of databases beyond Scopus (such as Web of Science, IEEE Xplore, etc.). By incorporating additional data sources, researchers can further validate their search results and enhance the comprehensiveness of their findings. Lastly, there is a need to develop technical means that can eliminate irrelevant search results more efficiently than the manual approach to streamline the research process and improve the accuracy of search results.

Author Contributions: Conceptualization, H.-S.N. and H.-C.D.; methodology, H.-S.N., H.-C.D. and Q.-P.M.; software, Q.-P.M. and J.H.; validation, M.P.; formal analysis, H.-S.N. and H.-C.D.; data acuration, Q.-P.M., J.H. and M.P.; writing—original draft preparation, J.M. and J.H.; writing—review and editing, Q.-P.M. and J.M.; visualization, Q.-P.M. and J.H.; supervision, M.P. and J.P. All authors have read and agreed to the published version of the manuscript.

Funding: This article has been written in connection with the Students Grant Competition SP2023/088 "Specific Research of Modern Manufacturing Technologies for Sustainable Economy" financed by the Ministry of Education, Youth and Sports and Faculty of Mechanical Engineering VŠB-TUO. This article was funded by the European Union under the REFRESH—Research Excellence For REgion Sustainability and High-tech Industries project number CZ.10.03.01/00/22_003/0000048 via the Operational Programme Just Transition.

Data Availability Statement: The data that used in this study are available from the corresponding author, upon reasonable request.

Conflicts of Interest: The authors do not have any conflict of interest that affect their research regarding their honesty and transparency.

References

1. Lu, Y.; Papagiannidis, S.; Alamanos, E. Internet of Things: A systematic review of the business literature from the user and organisational perspectives. *Technol. Forecast. Soc. Chang.* **2018**, *136*, 285–297. [CrossRef]
2. Nweke, H.F.; Teh, Y.W.; Mujtaba, G.; Al-garadi, M.A. Data fusion and multiple classifier systems for human activity detection and health monitoring: Review and open research directions. *Inf. Fusion* **2019**, *46*, 147–170. [CrossRef]
3. Dey, N.; Ashour, A.S.; Bhatt, C. Internet of Things Driven Connected Healthcare. In *Internet of Things and Big Data Technologies for Next Generation Healthcare*; Bhatt, C., Dey, N., Ashour, A.S., Eds.; Springer: Berlin/Heidelberg, Germany, 2017; pp. 3–12. [CrossRef]
4. Farahani, B.; Firouzi, F.; Chang, V.; Badaroglu, M.; Constant, N.; Mankodiya, K. Towards fog-driven IoT eHealth: Promises and challenges of IoT in medicine and healthcare. *Future Gener. Comput. Syst.* **2018**, *78*, 659–676. [CrossRef]
5. Holler, J.; Tsiatsis, V.; Mulligan, C.; Avesand, S.; Karnouskos, S.; Boyle, D. *From Machine-to-Machine to the Internet of Things: Introduction to a New Age of Intelligence*; Academic Press Inc.: Cambridge, MA, USA, 2014.
6. Thames, L.; Schaefer, D. *Cybersecurity for Industry 4.0*; Springer: Berlin/Heidelberg, Germany, 2017.
7. Dey, N.; Hassanien, A.E.; Bhatt, C.; Ashour, A.; Satapathy, S.C. (Eds.) *Internet of Things And Big Data Analytics toward Next-Generation Intelligence*; Springer: Berlin/Heidelberg, Germany, 2018; pp. 3–549.
8. Rawat, R.; Mahor, V.; Garg, B.; Chouhan, M.; Pachlasiya, K.; Telang, S. Lessons from COVID-19. In *Chapter Fifteen—Modeling of Cyber Threat Analysis and Vulnerability in IoT-Based Healthcare Systems during COVID*; Kaklauskas, A., Abraham, A., Okoye, K., Guggari, S., Eds.; Academic Press: Cambridge, MA, USA, 2022; pp. 405–425. [CrossRef]

9. Salatino, A.; Osborne, F.; Motta, E. ResearchFlow: Understanding the Knowledge Flow Between Academia and Industry. In *Knowledge Engineering and Knowledge Management*; Keet, C.M., Dumontier, M., Eds.; Springer: Berlin/Heidelberg, Germany, 2020; pp. 219–236.
10. Royle, P.; Kandala, N.B.; Barnard, K.; Wughn, N. Bibliometrics of systematic reviews: Analysis of citation rates and journal impact factors. *Syst. Rev.* **2013**, *2*, 74. [CrossRef]
11. Saheb, T.; Saheb, M. Analyzing and Visualizing Knowledge Structures of Health Informatics from 1974 to 2018: A Bibliometric and Social Network Analysis. *Healthc. Inform. Res.* **2019**, *25*, 61–72. [CrossRef]
12. Lu, K.; Liao, H. A survey of group decision making methods in Healthcare Industry 4.0: Bibliometrics, applications, and directions. *Appl. Intell.* **2022**, *52*, 13689–13713. [CrossRef]
13. Ellegaard, O.; Wallin, J.A. The bibliometric analysis of scholarly production: How great is the impact? *Scientometrics* **2015**, *105*, 1809–1831. [CrossRef]
14. Xu, L.D.; He, W.; Li, S. Internet of Things in Industries: A Survey. *IEEE Trans. Ind. Inform.* **2014**, *10*, 2233–2243. [CrossRef]
15. Lohiya, R.; Thakkar, A. Application Domains, Evaluation Data Sets, and Research Challenges of IoT: A Systematic Review. *IEEE Internet Things J.* **2021**, *8*, 8774–8798.
16. Ding, J.; Nemati, M.; Ranaweera, C.; Choi, J. IoT Connectivity Technologies and Applications: A Survey. *IEEE Access* **2020**, *8*, 67646–67673. [CrossRef]
17. Obaidat, M.A.; Obeidat, S.; Holst, J.; Brown, J. A Comprehensive and Systematic Survey on the Internet of Things: Security and Privacy Challenges, Security Frameworks, Enabling Technologies, Threats, Vulnerabilities and Countermeasures. *Computers* **2020**, *9*, 44. [CrossRef]
18. Page, M.J.; Graham, M.L. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *Int. J. Surg.* **2021**, *88*, 105906. [CrossRef] [PubMed]
19. Qi, B.; Jin, S.; Qian, H.; Zou, Y. Bibliometric Analysis of Chronic Traumatic Encephalopathy Research from 1999 to 2019. *Int. J. Environ. Res. Public Health* **2020**, *17*, 5411. [CrossRef] [PubMed]
20. Selva-Pareja, L.; Ramos-Pla, A.; Mercadé-Melé, P.; Espart, A. Evolution of Scientific Production on Health Literacy and Health Education: A Bibliometric Analysis. *Int. J. Environ. Res. Public Health* **2022**, *19*, 4356. [CrossRef]
21. Van Eck, N.J.; Waltman, L. Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics* **2010**, *84*, 523–538. [CrossRef]
22. Kim, A.-R.; Park, H.Y. Theme Trends and Knowledge-Relationship in Lifestyle Research: A Bibliometric Analysis. *Int. J. Environ. Res. Public Health* **2021**, *18*, 7503. [CrossRef]
23. Luo, X.; Wu, Y.; Niu, L.; Huang, L. Bibliometric Analysis of Health Technology Research: 1990 2020. *Int. J. Environ. Res. Public Health* **2022**, *19*, 9044. [CrossRef]
24. Small, H. Visualizing science by citation mapping. *J. Am. Soc. Inf. Sci.* **1999**, *50*, 799–813. [CrossRef]
25. Mora, L.; Deakin, M.; Reid, A. Combining co-citation clustering and text-based analysis to reveal the main development paths of smart cities. *Technol. Forecast. Soc. Chang.* **2019**, *142*, 56–69. [CrossRef]
26. Li, J.; Mao, Y.; Ouyang, J.; Zheng, S. A Review of Urban Microclimate Research Based on CiteSpace and VOSviewer Analysis. *Int. J. Environ. Res. Public Health* **2022**, *19*, 4741. [CrossRef]
27. Ustundag, A.; Cevikcan, E. *Industry 4.0: Managing The Digital Transformation*; Springer: Berlin/Heidelberg, Germany, 2017. [CrossRef]
28. Leung, X.Y.; Sun, J.; Bai, B. Bibliometrics of social media research: A co-citation and co-word analysis. *Int. J. Hosp. Manag.* **2017**, *66*, 35–45. [CrossRef]
29. Chaomei, C. Science Mapping: A Systematic Review of the Literature. *J. Data Inf. Sci.* **2017**, *2*, 1–40. [CrossRef]
30. Vaishya, R.; Javaid, M.; Khan, I.H.; Haleem, A. Artificial Intelligence (AI) applications for COVID-19 pandemic. *Diabetes Metab. Syndr. Clin. Res. Rev.* **2020**, *14*, 337–339. [CrossRef] [PubMed]
31. Mostafa, H.; Kerstin, T.; Regina, S. Wearable Devices in Medical Internet of Things: Scientific Research and Commercially Available Devices. *Healthc. Inform. Res.* **2017**, *23*, 4–15. [CrossRef]
32. Singh, R.P.; Javaid, M.; Haleem, A.; Suman, R. Internet of things (IoT) applications to fight against COVID-19 pandemic. *Diabetes Metab. Syndr. Clin. Res. Rev.* **2020**, *14*, 521–524. [CrossRef]
33. Yang, Z.; Zhou, Q.; Lei, L.; Zheng, K.; Xiang, W. An IoT-cloud Based Wearable ECG Monitoring System for Smart Healthcare. *J. Med. Syst.* **2016**, *40*, 286. [CrossRef]
34. Allam, Z.; Jones, D.S. On the Coronavirus (COVID-19) Outbreak and the Smart City Network: Universal Data Sharing Standards Coupled with Artificial Intelligence (AI) to Benefit Urban Health Monitoring and Management. *Healthcare* **2020**, *8*, 46. [CrossRef]
35. Slegers, K.; Kouwenberg, K.; Loučova, T.; Daniels, R. Makers in Healthcare: The Role of Occupational Therapists in the Design of DIY Assistive Technology. In Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (CHI '20), Honolulu, HI, USA, 25–30 April 2020; Association for Computing Machinery: New York, NY, USA, 2020; pp. 1–11. [CrossRef]
36. Robb, H.; Scrimgeour, G.; Boshier, P.; Przedlacka, A.; Balyasnikova, S.; Brown, G.; Bello, F.; Kontovounisios, C. The current and possible future role of 3D modelling within oesophagogastric surgery: A scoping review. *Surg. Endosc.* **2022**, *36*, 5907–5920. [CrossRef]

37. Verde, F.; Stanzione, A.; Romeo, V.; Cuocolo, R.; Maurea, S.; Brunetti, A. Could Blockchain Technology Empower Patients, Improve Education, and Boost Research in Radiology Departments? An Open Question for Future Applications. *J. Digit. Imaging* **2019**, *32*, 1112–1115. [CrossRef]
38. Xiong, H.; Jin, C.; Alazab, M.; Yeh, K.-H.; Wang, H.; Gadekallu, T.R.; Wang, W.; Su, C. On the design of blockchain-based ECDSA with fault-tolerant batch verification protocol for blockchain-enabled IoMT. *IEEE J. Biomed. Health Inform.* **2022**, *26*, 1977–1986. [CrossRef]
39. Arafeh, M.; Barachi, M.E.; Mourad, A.; Belqasmi, F. A blockchain based architecture for the detection of fake sensing in mobile crowd sensing. In Proceedings of the 4th International Conference Smart Sustainability Technology (SpliTech), Split, Croatia, 18–21 June 2019; pp. 1–6.
40. Chengoden, R.; Victor, N.; Huynh-The, T.; Yenduri, G.; HJhaveri, R.; Alazab, M.; Bhattacharya, S. Metaverse for Healthcare: A Survey on Potential Applications, Challenges and Future Directions. *IEEE Access* **2023**, *11*, 12764–12794. [CrossRef]
41. Lee, S.M.; Lee, D. Opportunities and challenges for contactless healthcare services in the post-COVID-19 Era. *Technol. Forecast. Soc. Chang.* **2021**, *167*, 120712. [CrossRef] [PubMed]
42. Mozumder, M.A.I.; Sheeraz, M.M.; Athar, A.; Kim, S.A.H.-C. Overview: Technology Roadmap of the Future Trend of Metaverse based on IoT, Blockchain, AI Technique, and Medical Domain Metaverse Activity. In Proceedings of the 24th International Conference on Advanced Communication Technology (ICACT), Pyeongchang, Republic of Korea, 13–16 February 2022; pp. 256–261. [CrossRef]
43. Yang, D.; Zhou, J.; Chen, R.C.; Song, Y.L.; Song, Z.J.; Zhang, X.J.; Wang, Q.; Zhou, C.Z.; Sun, J.Y.; Zhang, L.C.; et al. Expert consensus on the metaverse in medicine. *Clin. eHealth* **2022**, *5*, 1–9. [CrossRef]
44. Marzaleh, M.A.; Peyravi, M.; Shaygani, F. A revolution in health: Opportunities and challenges of the Metaverse. *EXCLI J.* **2022**, *21*, 791–792. [CrossRef]
45. Thomason, J. MetaHealth—How will the Metaverse Change Health Care? *J. Metaverse* **2021**, *1*, 13–16. Available online: https://dergipark.org.tr/en/pub/jmv/issue/67581/1051379 (accessed on 5 May 2023).
46. Yang, Y.; Siau, K.; Xie, W.; Sun, Y. Smart Health: Intelligent Healthcare Systems in the Metaverse, Artificial Intelligence, and Data Science Era. *J. Organ. End User Comput.* **2022**, *34*, 1–14. [CrossRef]
47. Cavanaugh, C. Top 5 Challenges with Healthcare Interoperability (How to Solve Them). 2021. Available online: https://www.healthjump.com/blog/5-challenges-with-healthcare-interoperability (accessed on 10 May 2023).
48. DelveInsightBlog. How Metaverse Is Set to Transform the Healthcare Dynamics? 2022. Available online: https://www.delveinsight.com/blog/metaverse-in-healthcare (accessed on 10 May 2023).
49. Ameen, I. Metaverse in Healthcare—New Era Is Coming True. 2022. Available online: https://healthcarebusinessclub.com/articles/healthcare-provider/technology/metaverse-in-healthcare/ (accessed on 10 May 2023).
50. Teh, D. Is the Metaverse the Future of Health? 2022. Available online: https://healthmatch.io/blog/is-the-metaverse-the-future-of-health (accessed on 10 May 2023).
51. Chaudhry, S.A.; Yahya, K.; Garg, S.; Kaddoum, G.; Hassan, M.M.; Zikria, Y.B. LAS-SG: An elliptic curve-based lightweight authentication scheme for smart grid environments. *IEEE Trans. Ind. Inform.* **2022**, *19*, 1504–1511. [CrossRef]
52. Xi, N.; Chen, J.; Gama, F.; Riar, M.; Hamari, J. The challenges of entering the metaverse: An experiment on the effect of extended reality on workload. *Inf. Syst. Front.* **2023**, *25*, 659–680. [CrossRef]
53. JosephNg, P.S.; Gong, X. Technology Behavior Model—Impact of Extended Reality on Patient Surgery. *Appl. Sci.* **2022**, *12*, 5607. [CrossRef]
54. He, L.; Liu, K.; He, Z.; Cao, L. Three-dimensional holographic communication system for the metaverse. *Opt. Commun.* **2023**, *526*, 128894. [CrossRef]
55. Taylor, L.; Dyer, T.; Al-Azzawi, M.; Smith, C.; Nzeako, O.; Shah, Z. Extended reality anatomy undergraduate teaching: A literature review on an alternative method of learning. *Ann. Anat.* **2022**, *239*, 151817. [CrossRef] [PubMed]
56. de Fortuny, E.J.; Martens, D.; Provost, F. Predictive Modeling with Big Data: Is Bigger Really Better? *Big Data* **2013**, *1*, 215–226. [CrossRef] [PubMed]
57. Herland, M.; Khoshgoftaar, T.M.; Bauder, R.A. Big data fraud detection using multiple medicare data sources. *J. Big Data* **2018**, *5*, 1–21. [CrossRef]
58. Karatas, M.; Eriskin, L.; Deveci, M.; Pamucar, D.; Garg, H. Big Data for Healthcare Industry 4.0: Applications, challenges and future perspectives. *Expert Syst. Appl.* **2022**, *200*, 116912. [CrossRef]
59. Awan, U.; Hannola, L.; Tandon, A.; Goyal, R.K.; Dhir, A. Quantum computing challenges in the software industry. A fuzzy AHP-based approach. *Inf. Softw. Technol.* **2022**, *147*, 106896. [CrossRef]