Technological Forecasting & Social Change 184 (2022) 122001

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

journal homepage: www.elsevier.com/locate/techfore

IoT in healthcare: A scientometric analysis

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ARTICLE INFO

Keywords:
IoT
Scientometric analysis
Topic detection
Research dynamics
Healthcare industry

ABSTRACT

This paper reviews scientific articles and patents about Internet of Things (IoT) in healthcare. The aim is to explore both the domain of research and the one of practice simultaneously. We compare the annual growth, the country production, and the trend topics of publications and patents, by focusing on the most relevant themes concerning the IoT in the healthcare industry. The analysis started with the selection of the publications and patents for the period 2015–2020. Since this comparative analysis between scientometric data in healthcare is new, the findings of this study can represent the basis for future studies to determine novel research opportunities on IoT. The study provides scholars with a better understanding of IoT research in healthcare and simultaneously extends knowledge of entrepreneurship in this field. Practitioners may benefit from this review to understand new and underexplored opportunities.

1. Introduction

The role played by the information systems has grown everywhere, especially in the healthcare industry (Pang, 2013). From electronic health records to cloud-based systems, the health industry has always benefited from information technology (IT). As IT develops, information systems become the key to improving healthcare and its management (Martínez-Caro et al., 2018). This has resulted in the search for new business models aimed at facilitating access to health services by all the actors involved, through a greater circulation of information (Verdegem and De Marez, 2011).

The Internet of Things (IoT) is one of the latest IT uses in healthcare. The IoT can be considered as the interconnection of intelligent objects or devices, via the Internet, which gives rise to new applications and innovative services (Lu et al., 2018). These objects, having extensive human detection capabilities, are used in the medical field for remote health monitoring, early diagnosis, and elderly care (Nweke et al., 2019). These IoT applications in the healthcare sector can improve the well-being of patients and reduce the costs of services, for example by avoiding unnecessary hospitalizations and ensuring better care for people who are in critical situations. IoT-based healthcare services, acting on the entire value chain, will generate a revolution in the healthcare sector (Dey et al., 2017).

Much research has been produced out over the past years on projects related to the IoT in healthcare. IoT research has grown rapidly especially concerning studies dealing with the applications of innovative products in healthcare (Papa et al., 2020; Martínez-Caro et al., 2018; Canhoto and Arp, 2017). For example, Islam et al. (2015) examined IoT-based industrial applications and trends in healthcare. Their study analyzed various IoT and eHealth policies and regulations around the world to determine how they can facilitate economies and societies in terms of sustainable development. However, to date, the reviews regarding the use of IoT in healthcare are not numerous. The few we have found started using bibliometric techniques to study the literature on IoT applications in healthcare. For example, Saheb and Izadi (2019) recently conducted a review of articles on IoT big data analytics and articles on fog computing in healthcare. Similarly, Lu et al. (2018), in the business sector, reviewed the business literature related to IoT adopting the user perspective and manufacturing organizations.

Differently from previous research, our exploratory work aims to simultaneously analyze both the domain of research and the one of practice about IoT in the healthcare industry to verify the degree of alignment between them. We draw the research and patent trend topics over time and investigate whether there is a time asymmetry between research and practice. Our study effort is to provide more practical answers to practitioners and researchers. Indeed, our research questions are: RQ1) Do IoT research and practice converge towards the healthcare industry? RQ2) What are the main key conceptual subfields of research

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https://doi.org/10.1016/j.techfore.2022.122001
Received 8 February 2022; Received in revised form 25 July 2022; Accepted 25 August 2022
Available online 8 September 2022

about IoT in the healthcare industry and how have they evolved? Therefore, the main theoretical contribution of this paper consists of the identification of a new approach to analyze the evolution of issues in the academic and industrial world. This gives the possibility to predict the impact of emerging research topics on the industrial sector and to compare the information contained in both patents and publications.

The study is articulated as follows. Section 2 presents the literature review on the role of IoT in healthcare. Section 3 describes the research materials and methods we used to collect and analyze the data. Section 4 illustrates the main findings and Section 5 discusses them with implications for research.

2. Literature review

2.1. IoT in healthcare

IoT was born in 1999, when Kevin Ashton tried to connect objects to the internet via RFID tags (designed to make it easier for computers to manage objects) (Ashton, 1999; Bandyopadhyay and Sen, 2011; Ma, 2011; Da Xu et al., 2014; Li et al., 2015). There are numerous definitions of IoT in the literature. Some of them prefer the type of connectivity (Radio Frequency Identification, Wireless Sensor Network), that binds different objects, and others focus on the type of object (services and applications) and its application domains (smart cities, traffic congestion, waste management, structural health, security, emergency services, logistics, retails, industrial control, and health care).

The IoT is already a reality in many fields, but it remains quite a new topic in the healthcare sector. Probably, this is due to healthcare organizations that operate in a highly regulated sectors. Thanks to the continuous development of wearables and smartphones, the different IoT-based healthcare devices have transformed the traditional healthcare system into a smarter one, closer to the needs of patients. It leverages IoT innovations to move away from the old hospital-centered practice and to create a new patient-centered way of acting. Bhatt and Bhatt (2017) stated that IoT has revolutionized healthcare industry by generating new opportunities for personalized eHealth and mHealth services.

In the healthcare context, IoT can therefore be defined as a network of intelligent sensing devices and physical objects that are digitally connected for the collection, monitoring, and control of healthcare data. In fact, through the detection sensors incorporated in the objects worn (gloves, watches, glasses, etc.), which are connected via wired or wireless networks to tablets or smartphones, patient data can be immediately consulted by doctors and patients themselves (Farahani et al., 2018; Mital et al., 2018).

Many researchers emphasized the importance of the role played by IoT in different aspects of health. Dey et al. (2018) wrote about how IoT has improved disease management through an innovative market depth assessment that includes supplier analysis, growth drivers, industry value chain, and quantitative assessment. Thames and Schaefer (2017) said how IoT has enabled automation in clinical trials for patients, providing high insights into the value in healthcare. Holler et al. (2014) argued about the reduction of costs in health care and the emergence of new health care systems due to the IoT.

Moreover, the IoT has provided the healthcare industry with the means to improve its operational efficiency. Through the use of IoT innovations, hospitals have been able to optimize the information flows facilitate communication with the patients and their families, integrate the various data concerning the patient even if coming from other hospitals or centers that they are part of the network.

2.2. Scientometric analysis for exploring research and patent fronts

The significance of IoT in the healthcare industry will become stronger. According to Gartner estimates, every two years the IoT device market will double in value (Egham, 2017). IoT entrepreneurship in the healthcare sector is deemed to grow, with a wide and progressive spread of applications.

Ardito et al. (2018) mapped the innovation dynamics in the general IoT domain. They claimed that firms, especially in industries like telecom and ICT, are more innovative than research and academic centers, but inter-organizational collaborations are infrequent. Ceipek et al. (2021) showed that "underperforming firms are more willing to engage in the emerging IoT domain" than superior prior firm performance.

At the same time, the attention of researchers is growing (Ustundag and Cevikcan, 2017), but an open and bidirectional flow of ideas and information between academia and industry is critical to push innovation in this field (Larivière et al., 2018).

Today, there is not a clear framework of what research has produced so far, both from an entrepreneurial innovation side and from the regulators, professionals, and patients one. This paper aims to fill this gap using scientometric methods for analyzing academic publications and patents data. Scientometrics is the discipline that applies quantitative analysis to scientific data, such as publications, patents, clinical trials, grants, and all other output of science. Salatino et al. (2020) proposed an approach that integrates semantic technologies and machine learning to analyze, monitor, and predict the flow of knowledge between academia and industry. Unlike this contribution, we compared the trends of publications and patents and extract the research front of research.

We used the Bibliometrix R package as scientometric software tool (Aria and Cuccurullo, 2017). A recent survey on bibliometric software tools concluded that Bibliometrix "stands out since it incorporates a great variety of different analyses" and for Biblioshiny web app user-friendliness (Moral-Muñoz et al., 2020). For instance, it allows to develop a performance analysis through impact metrics on three different units (journals, authors, and documents) and to build a bibliometric network for visualizing the conceptual, intellectual, and social knowledge structures. Bibliometrix also performs longitudinal conceptual (burst detection and thematic evolution), intellectual (spectroscopy/RPYS and histograph), and geospatial analysis.

3. Materials and methods

We set the state of the art of the IoT in healthcare, simultaneously examining the domain of research (publications) and the domain of practice (patents). The Dimensions database from 2015 to 2020 was systematically searched to identify all publications and patents related to IoT in healthcare. Various bibliometric method was used for the analysis.

3.1. Data collection

We queried the Dimensions database. It offers the most comprehensive collection of linked data in a single platform from scientific articles, altmetric data, patents, grants, clinical trials to policy documents (Martín-Martín et al., 2020). We used the following search terms: "Internet of Things" AND "Health*" in the title, abstract, and keywords fields over the period 1999–2020, focusing only on English documents. The analysis did not include 2021 because this year was still in progress when the data were downloaded. This query returned 5878 publications and 5457 patents.

We applied some exclusion criteria. First, we have narrowed the timespan, considering the six-year period (2015–2020). It is only starting from 2015 that the topic of IoT in health assumes a significant growth, from 1999 to 2014 there are only 153 publications and 1249 patents. Second, we selected only articles and proceedings, excluding other document types (1239 records are excluded). Our final dataset is therefore composed of 4432 publications and 4208 patents (Fig. 1). Data were downloaded in CSV format, filtered, and then analyzed using the tool Bibliometrix (Aria and Cuccurullo, 2017). It is an open-source tool for quantitative research in scientometrics and bibliometrics and today it is considered the most complete, integrated, and user-friendly

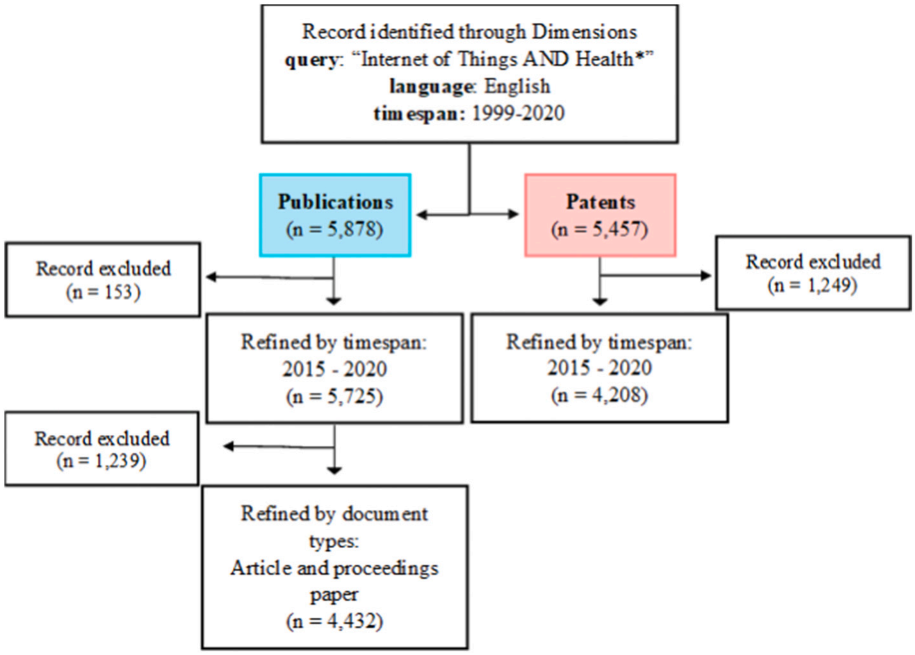

Fig. 1. Data collection workflow.

bibliometric tool (Moral-Muñoz et al., 2020).

3.2. Data analysis

3.2.1. Scientific production

We conjointly analyzed the scientific production of publications and patents concerning annual production and country production. The annual production allowed us to understand the theme's development degree over time while the country production allowed us to understand the theme's globality level. Furthermore, we discussed the role played by key organizations (both public and private) and especially by discussing the differences between research (publications) and practice (patents).

3.2.2. Trend topic

The analysis of the trend of patents and publications allowed us to compare the evolution of the research and practice topics for IoT in the healthcare industry.

Trend topic analysis is included in the Bibliometrix R package. The idea is to build a graphic representation where each topic (by topic means a word) is assigned a year representing, synthetically, the time distribution of the occurrences of the topic itself. The reference year for each theme is identified using the median of the distribution of events in the considered period.

We started by extracting all the keywords from each patent and publication. Using the Bibliometrix R package, we extracted the keywords from each title. Afterwords, we refined the keywords to ensure consistency. For example, some words have been replaced with acronyms (e.g. machine learning, artificial intelligence). So, for each word, we first constructed the words time distribution, that is, a matrix of words for years in which there is the frequency of a word in patents and publications scattered over a year. Once these occurrence distributions have been obtained, the median, the first and the third quartiles of the frequency distributions have been calculated for each term and then each term was assigned the median year which represents the position index of the use of that term over time. Consequentially, we have combined the topics, patents, and publications, to analyze the alignment or the time asymmetry by which research and practice move reciprocally. The results are projected into a graph. The trend topic graph is a scatter plot where time is indicated on the horizontal axis while the most frequent terms are indicated on the vertical axis. Each bubble on the graph represents the frequency of the topic in the median year. Bubble size is proportional to the term occurrence. The period in which a term is used is indicated with a gray bar connecting the first and third quartiles.

3.2.3. Conceptual structure

We analyzed the conceptual structure of publications. This bibliometric analysis helps generate clusters that enable a broader view of divergent research in a specific scientific field (Börner et al., 2003). The methodological foundation of the conceptual structure is the idea that the co-occurrence of key terms (authors keywords, journals keywords, indexing keywords such as ISIWoS' keywords Plus, or any combination of them) describes the content of the documents in a dataset (Callon et al., 1991). The more keywords two documents have in common, the more similar the two publications are, and the more likely they come from the same research field or research specialty at a higher level (Cobo et al., 2011). The keywords, which appear together in a document, will be related in a co-words network. By applying the Louvain clustering algorithm on the co-word network, it is possible to highlight the different themes of a given domain. This thematic network is plotted on a bi-dimensional matrix, where the axes are a function of the Callon centrality and the Callon density of the thematic map. Centrality can be read as the relevance of the theme in the entire research field. Density is intended as a measure of the theme's development degree.

Bi-dimensional matrix defines four quadrants concerning different themes (Callon et al., 1991; Courtial, 1994; Coulter et al., 1998; He, 1999; Cahlik, 2000; Aria et al., 2020): (i) motor themes (upper right quadrant) that are highly relevant and very well developed; (ii) basic themes (lower right quadrant) that are highly relevant but not well developed; (iii) emerging or declining themes (lower left quadrant) that are low relevant and developed; (iv) niche themes (upper left quadrant) that are low relevant but very well developed.

Each theme represented in the dimensional matrix is a network cluster. The bubble name is the word, belonging in the cluster, with the higher occurrence value. The bubble size is proportional to the cluster word occurrences.

By means of Bibliometrix tool (Aria and Cuccurullo, 2017), the thematic evolution analysis considered 250 keywords, with the minimum cluster frequency set to 2 and the inclusion index weighted by word-occurrences set to 0.1. For better clarity and interpretability of the results, we plotted 1 keyword for each cluster. After an initial analysis, we have reformulated some keywords to ensure greater clarity of the final map.

Finally, consistently with what is stated in the literature and looking at the distribution of publications per year, we decided to split our collection into two-time slices.

By dividing the time interval into time slices, it is possible to study and plot the topic evolution (in terms of trajectory along time). It is also possible to highlight the tendencies of some topics to merge together, or of a topic to split into several themes, over time. Operating a single cutting in 2017, we have obtained two thematic maps: 2015–2017 (Fig. 6) and 2018–2020 (Fig. 7).

4. Findings

4.1. Patent and publications

a. Annual production

The IoT is a fast-growing topic in the healthcare industry (Ustundag and Cevikcan, 2017). However, it is only in the past 6 years that the IoT theme has shown a surge (Fig. 2). In the fifteen years after its birth (1999–2014), scientific production on IoT in healthcare has grown very slowly, with a maximum of 62 publications in 2014 alone. This means that IoT research in the healthcare sector is a pretty new topic. Fig. 3 jointly shows the annual production of publications and patents related to the IoT in the healthcare sector over the past six years. Over the past six years (2015–2020), the number of articles has gradually increased with the number of articles peaking in 2020 at 1458 articles. Such a large number of publications indicates that academic production is intensifying. This is likely also due to companies' very recent interest in developing new and improved IoT innovations in the healthcare sector. Fig. 3 reports the annual production of patents related to IoT innovations in the healthcare sector also shows a significant increase over the past six years. In the first period (2015–2017) 818 patents are produced (20 %) compared to 3390 produced in the second period (2018–2020).

b. Country scientific production

The analysis of country scientific production shows that the number of documents where at least one author comes from a particular country, varies considerably between scientific and patent production.

Fig. 4 shows, patent (left) and, publications (right) production at country level, concerning the IoT in the healthcare sector. The most productive countries for IoT-related publications in the healthcare sector are India (n = 668, 15 %), followed by United States of America (USA) (n = 379, 8.5 %), China (n = 227, 5 %), and United Kingdom (United Kingdom) (n = 146, 3 %). As for patents, instead, South Korea is the country with the highest intensity of patents and specialized in the IoT (n = 3819, 90 %), followed by India (n = 223, 5 %), China (n = 65, 1.5 %), USA (n = 44, 1 %).

The issue of IoT in the health industry is now a global issue for research (102 producing countries), while it remains a niche topic for patents (22 producing countries). This is probably due to the high level of specialization and strong innovative efforts in the IoT patent domain of some Eastern countries.

c. Key organizations

In Table 1, we analyze the major patent and publication producing organizations. Similarly, to country scientific production, the most productive Academic Institutions are Indian universities, such as Anna University, Vellore Institute of Technology University (VIT), Visvesvaraya Technological University (VTU), and Amity University.

Among the organizations producing IoT patents in the healthcare sector, we find Samsung, a global player in mobile telecom. The South Korean company ranks first covers 87.7 % of Health IoT patent production. This company dominates the market for connected objects and wearable devices in the healthcare sector. The second patent producer is US-based IBM. Its product Watson Health can use IoT to support health professionals with big data and AI. Other patent producers are (i) Qualcomm, another wireless telecom player, (ii) government research institutes, such as the Indian Council of Scientific and Industrial Research (CSIR) and Electronics and the South Korean Telecommunications Research Institute (ETRI), (iii) as well as private universities, such as the Indian Lovely Professional University (LPU) and the South Korean Sungkyunkwan Research and Business University.

Table 2 reports the top impactful ten Samsung Health IoT patents, that registered in different countries to extend the rights coverage internationally. These patents concern Communications Technologies, Information Systems and Computing Sciences, Artificial Intelligence, and Image Processing.

d. Trend topic

The joint analysis of the topics covered in publications and patents allows to understand the degree of alignment between research and practice. Looking at Fig. 5, the topics covered by the research are

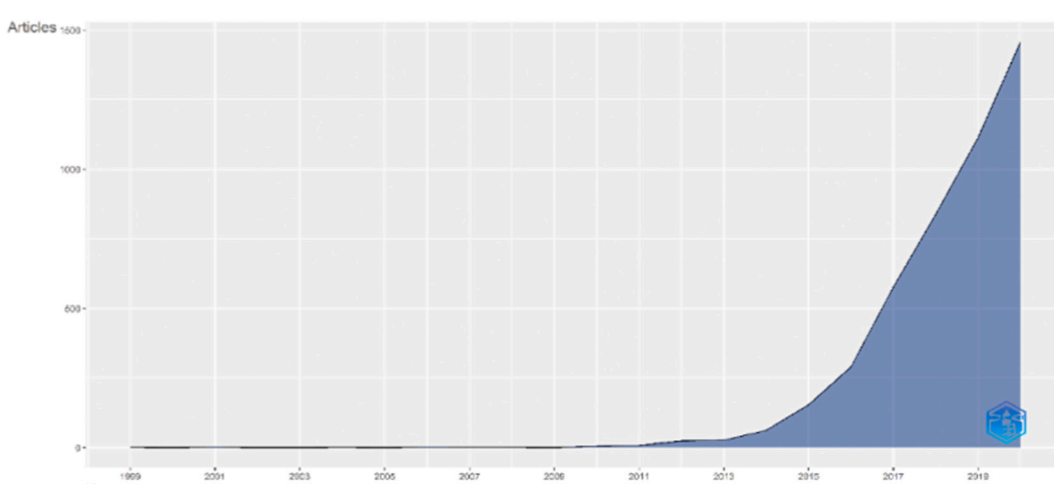

Fig. 2. Annual scientific production (1999–2020).

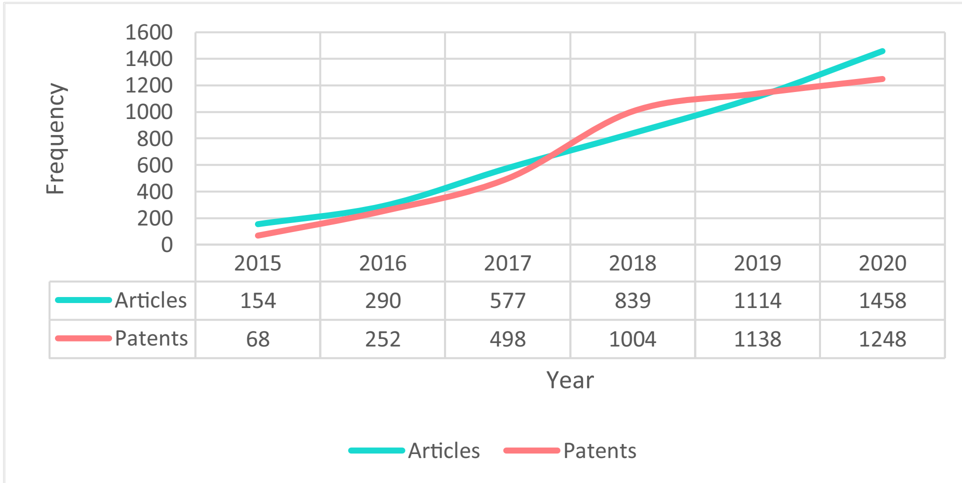

Fig. 3. Annual articles and patents production.

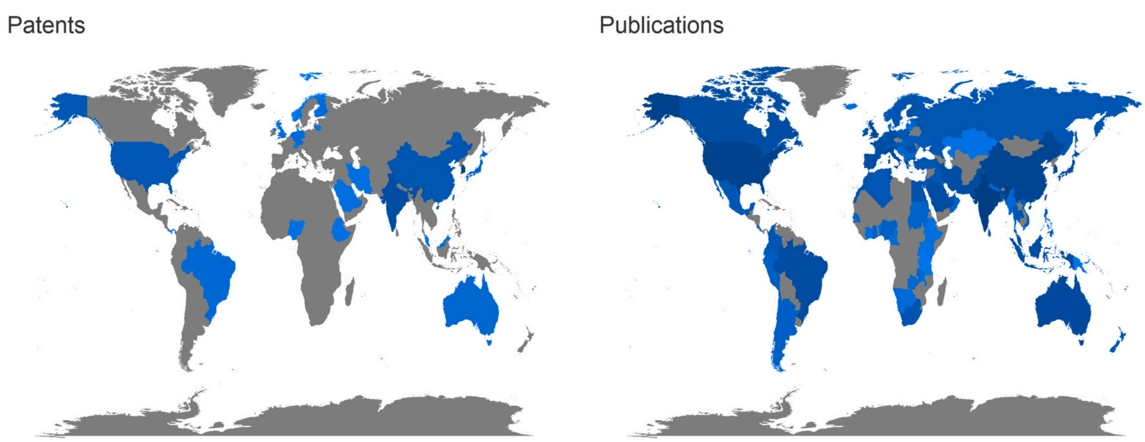

Fig. 4. Patents and publications country scientific production.

Table 1
Most patent and publication producing organizations.

Key organizations	Patents	Key organizations	Publications
Samsung Electronics Co Ltd	3691	Anna Univ	79
Ibm	9	Vit	62
Lpu	9	King Saud Univ	45
Qualcomm Inc	7	Vtu	37
Csir	5	Qatar Univ	34
Sungkyunkwan Res & Bus Univ	5	Comsats Univ Islamabad	32
Univ Korea Res & Bus Found	5	Univ Of Technology Sydney	27
Postech Acad Ind Found	4	Amity Univ	25
Univ Inha Res & Business Found	4	Univ Of California	24
Etri	4	Univ Of Turku	24

indicated in blue, while those addressed by the patents are in red. To increase the readability of the graph, for each year only the first 5 topics are reported in decreasing order of frequency. In the first period (2015–16), the IoT innovations with applications in the healthcare sector are born. In fact, among the keywords of patents, we find “transmission-reception”, “sensors”, and “connected devices”. In this same period, the research already focuses on topics such as “legal”, “assurance”, “share” and “cloud-IoT”. Indeed, research questions in this period concern, the legal challenges associated with telehealth and the

Table 2
Samsung’s impactful patents: top 10.

Patent title	Total citations	Numbers of registrations
Method and apparatus for transmitting group message to user equipment (ue)	194	5
Method and apparatus for ue signal transmission in 5 g cellular communications	138	4
Apparatus and method for signaling system information	117	10
Method and apparatus for allocating resources for v2x communication	109	3
Method and device for updating profile management server	109	5
Structure of mac sub-header for supporting next generation mobile communication system and method and apparatus using the same	86	22
System and method of paging in next generation wireless communication system	81	13
Method and apparatus for pairing a wearable device and a smart device	78	3
Method and apparatus for handling collisions in next generation communication system	66	3
Method for activating pscell and scell in mobile communication system supporting dual connectivity	65	7

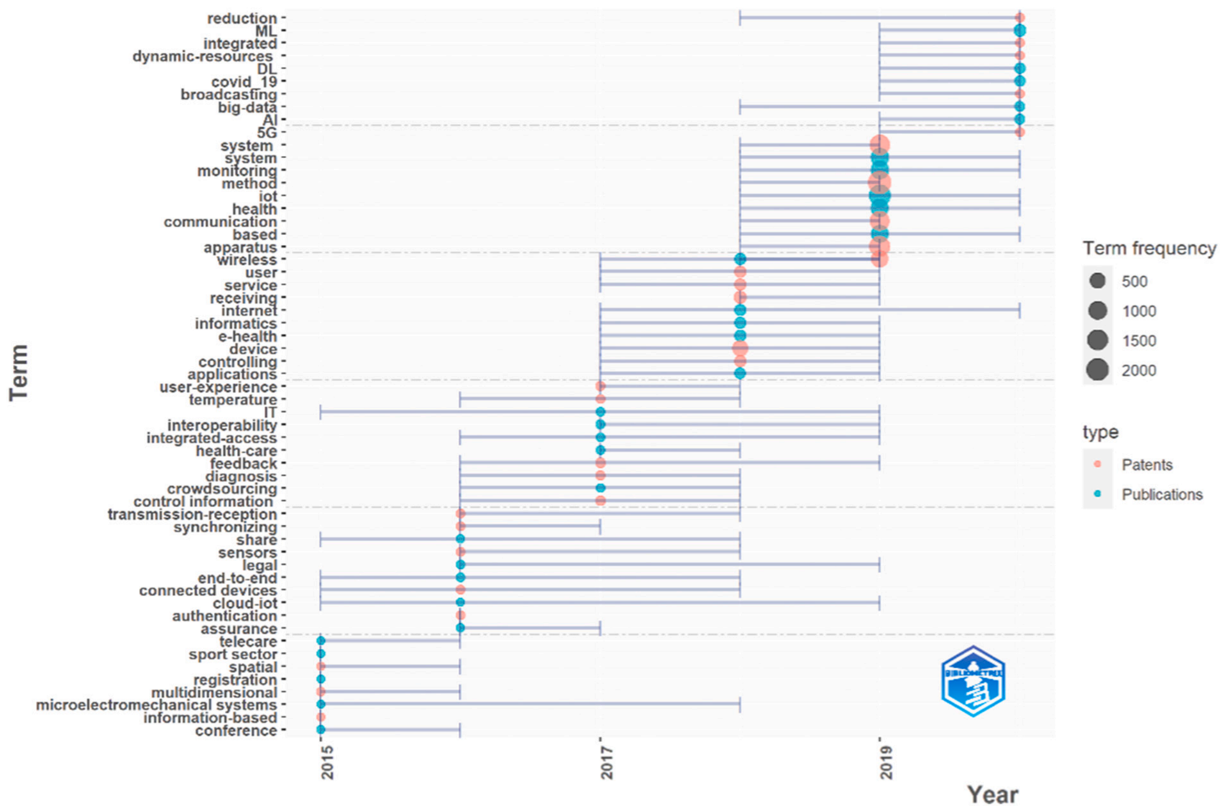

Fig. 5. Patents and publications trend topic.

need to have a wide-ranging governance approach to manage a global resource such as the IoT (Suciu et al., 2015; Conchon and Bricon-Souf, 2016).

In the following period (2017–18), the patents related to all technologies aimed at improving user experience and service deriving from the use of the first IoT applications in healthcare sector. The keywords are "feedback", "control information", "user", "diagnosis". In the same period, research already focuses on topics such as "IT" (information technology), "software", "wireless", and "internet". The health sector has always benefited from IT and the period in which research addresses this topic is very large (2015–2019). However, the interconnection among many different devices highlights how the existing hardware infrastructure is no longer usable. IoT research, therefore, generates the issue of identifying suitable software to support the internet connectivity of new existing equipment (Chatterjee et al., 2017; Wu et al., 2018; Fati et al., 2018; Murali et al., 2018; Rajan and Rajan, 2018; Beach et al., 2018).

Finally, in 2019–20 the patents related to the possibility of having higher levels of connectivity to increase speed, reduce latency and improve the flexibility of wireless services. Among the keywords of the patents, we detect "wireless", "5G", "dynamic resources", and "communication". Instead, the research front monitors the use in healthcare of existing smart objects and web protocols that can facilitate interoperability and communication of heterogeneous devices. In fact, among the keywords of the publications, we find "AI" (artificial intelligence), "DL" (deep learning), "ML" (machine learning), and "big data". (Li et al., 2020; Sakib et al., 2020; Santos et al., 2020; Rodrigues et al., 2020; Zikria et al., 2020).

Research publications and patents are an ideal means of analyzing the knowledge generated by the academia and entrepreneurship (Meloni et al., 2021; Ankrah and Omar, 2015; Ankrah et al., 2013). This joint analysis of the topics covered in practice and in the research allows us to understand that the practice shows a delay compared to the research. In particular, the topics covered on the practice front show the continuing concern of developers to identify and use the most advanced technologies to simplify and improve the customer experience.

Instead, the topics dealt with by the research front highlight the opportunities, legal challenges, and equipment that could be proposed by the practice to solve the main difficulties of the users.

4.2. Focus on research: thematic evolution

Below, we report the results of the analysis of the thematic evolution of publications in the two periods considered (2015–2017–2018–2020). Looking at the Callon centrality and density, we analyze the motor themes, the basic themes, the emerging or declining themes, and the niche themes. Comparing the thematic map of the first period and the second period considered, we analyze and trace the evolution of the themes (in terms of trajectory on the theme).

4.2.1. Motor themes

Motor themes are highly relevant and well developed in research, as they have high levels of centrality and density.

4.2.1.1. First period. In the period 2015–17 (Fig. 6), there is just one motor theme, that is "aged". Older people are an important and highly developed topic because they use most of the health services and need more assistance. The most relevant keywords in this cluster are "blood glucose", "diabetes mellitus", and "anti-bacterial agents". Several studies from our collection underline that IoT research was born precisely to be able to monitor diseases related to old age (Oliveira et al., 2016; Onoue et al., 2017).

4.2.1.2. Second period. In the period 2018–20 (Fig. 7) among the motor themes, we find "female" which becomes the word with the highest occurrence value, followed by "middle age". This means that the average age of users in studies is decreasing and that women are prevalent in the surveys. Therefore, the cluster that in the first period

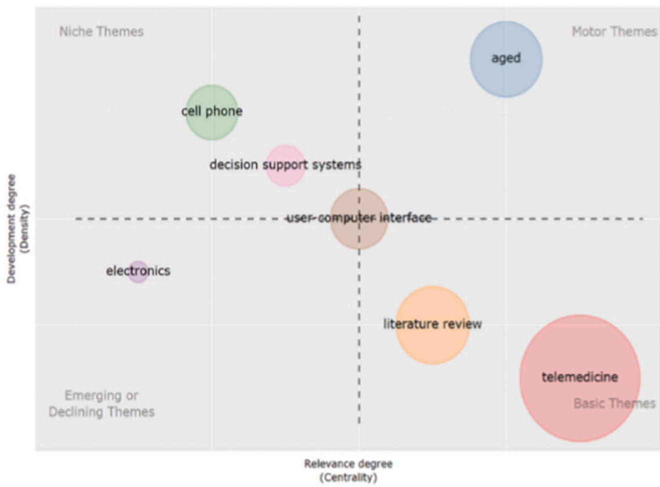

Fig. 6. Thematic map about time slice 2015–2017.

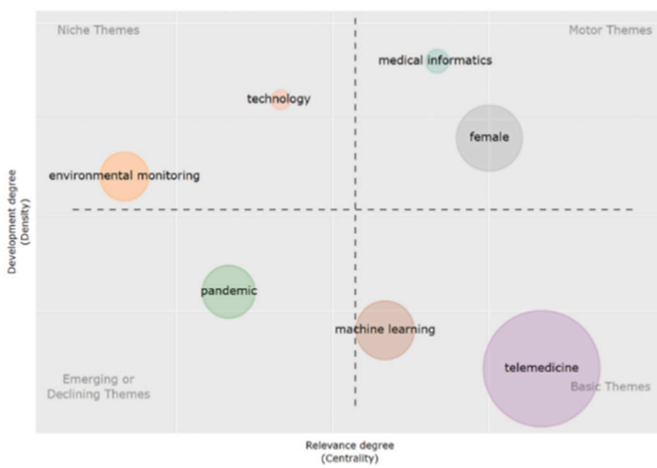

Fig. 7. Thematic map about time slice 2018–2020.

consisted of the "aged" theme has evolved. These changes are related to the greater importance attributed to issues such as postpartum care (Than et al., 2018), the risk of senile dementia which is higher in women than in men (Rostill et al., 2018; Enshaeifar et al., 2018), but also to issues concerning IoT innovations such as wearable equipment for physical activity (Canhoto and Arp, 2017; Kao et al., 2019).

Among the motor themes, in this period, we also find "medical informatics". In our collection, we find all the studies concerning medical informatics used for patient monitoring (Dhevi et al., 2018), for pre-and-post hospital patient care (Schiavone et al., 2020), but also important reviews on methods IT for IoT-enabled healthcare (Yang and Xu, 2018).

4.2.2. *Basic themes*

The second quadrant concerns basic themes. They are low developed in research but very relevant themes. The clusters that fall into this quadrant are characterized by low levels of density and high levels of centrality.

4.2.2.1. *First period.* In the period 2015–17 (Fig. 6), there are two basic themes. The first is "literature review". Keywords such as "bibliometrics", "databases", "bibliographic", and "data mining" flow into this cluster. This theme is probably an emerging theme since, as we also state in Section 2, the bibliometric analysis of IoT research in healthcare is recent and almost all the reviews included in our collection are bibliometric (Lee et al., 2018; Saheb and Izadi, 2019; Alabdulkarim et al., 2019).

Among the basic themes, in this period, we also find "telemedicine" intended as a way of providing services. This cluster includes the studies concerning public health (Rathore et al., 2016), electronic medical supports (Jeon and Ha, 2016; Sonnis et al., 2017), wearable electronic devices (Kumari et al., 2017; Xin and Wu, 2017; Marin et al., 2017) and studies concerning the key technology to enable health monitoring systems oriented towards IoT (Hindia et al., 2016).

4.2.2.2. *Second period.* In the period 2018–20 (Fig. 7), we find "telemedicine" among the basic themes but looking at the papers that fall within this cluster we see that something has changed in the delivery of health services between the first and second period. Lavanya et al. (2018) propose an innovative system called "The Smart Chair" that is a new health monitoring system for telemedicine developed on sensor technologies and safety. This telemedicine-based monitoring system ensures health services to people anywhere, anytime. Other research investigates the fact that information gleaned from IoT devices can help clinicians identify the best treatment process for patients and achieve accurate and expected outcomes (Sigu et al., 2020; Todorova and Andonova, 2020).

In this period, among the basic themes, we also find "machine learning". Many of the papers in our collection consider machine learning for the detection of falls (Santos et al., 2019) or, more generally, to analyze the activities of daily life in people (Enshaeifar et al., 2019).

4.2.3. *Emerging or declining themes*

The third quadrant shows the emerging or declining themes. The clusters in this quadrant are formed by less important and poorly developed themes in research and this occurs in two moments in the life of a topic, that is when it emerges or declines.

4.2.3.1. *First period.* In the period 2015–17 (Fig. 6), there is one theme: "electronics". Keywords such as "water", "carbon atoms", and "environmental monitoring" (Brauch, 2015; Jeon and Ha, 2016) are part of this theme. This cluster concerns all the electronic equipment that is used for health research in the environmental field. Following the trajectory of this cluster, in the following timeslice (Fig. 7), it becomes a niche theme, that is a highly developed topic but by a small group of researchers (sector niche). In the period 2018–20, the most used keyword is no longer electronics, but "environmental monitoring". This evolution in research reflects the fact that even if attention to the environment and health has always been relevant, it is only starting from the last 2 years that there has been a change in research aimed at giving greater attention to environmental issues for healthy humans (Fu and Wu, 2018; Mukherjee et al., 2019; Marques et al., 2019; Bublitz et al., 2019; Lin et al., 2020; Kim et al., 2020).

4.2.3.2. *Second period.* In the period 2018–20 (Fig. 7) among the emerging themes, we find "pandemic" which becomes the word with the highest occurrence value. The most relevant keyword in this cluster is "artificial intelligence". The pandemic theme is certainly an emerging one as it has come to light recently, in the form of "coronavirus infection". All the studies concerning the IoT applications implemented to counter the coronavirus fall into this cluster (Vaishya et al., 2020; Singh et al., 2020; Bayram et al., 2020; Kumar et al., 2020). Despite the great interest of the research, this topic is limited in time. So, it is an emerging theme but if we studied its evolution overtime, it would become a declining theme.

4.2.4. *Niche themes*

The fourth quadrant reports the niche themes, that is, the highly developed but not very relevant for research.

4.2.4.1. First period. In the period 2015–17 (Fig. 6), there are two niche themes. The first is the "cell phone". Cell phones are often used by research projects as monitoring devices. The nature of the multiple sensors of cell phones, GPS tracking, BlueTooth, and their direct Internet connection makes these devices particularly useful in IoT solutions (Jian and Chen, 2015; Qi et al., 2018).

The other niche theme is "decision support systems". Words such as "health information management", "organizational objectives", and "practice guidelines" are part of this second cluster. Several studies have focused on how IoT can improve the quality of life of patients by facilitating some of the basic tasks they have to perform daily. In this sense, the decision support system can be moved from the human side to the machine side (Gerdes et al., 2015; Farahani et al., 2018; Martínez-Caro et al., 2018).

4.2.4.2. Second period. In the period 2018–20 (Fig. 7) among the niche themes, we find "environmental monitoring", which we have already explained to be the thematic evolution of "electronics", and we find "technology" as well. This cluster includes all studies regarding technological developments and new technological trends that will influence the future of health services (Bodur et al., 2019), the opportunities associated with IoT innovations in health (Gopal et al., 2019), and the challenges that health institutions face in adopting medical equipment with detection capabilities (Giordanengo, 2019).

4.2.5. Central themes

4.2.5.1. First period. In the period 2015–17 (Fig. 6), in the center of the map, we find the "user-computer interface". This cluster is characterized by average levels of centrality and density. Words such as "self-help devices", "speech disorders" are part of this third cluster. In almost all research relating to the use of IoT innovations in healthcare, we find the issue of user-computer interface. In order to score the expected results, these innovations have to be used extensively. Therefore, the user-computer interface becomes a central topic for research (Konstantinidis et al., 2015, Ahmed et al., 2015; Cudd and de Witte, 2017; Canhoto and Arp, 2017).

5. Conclusions

Our paper aims to simultaneously explore the fronts of research (publications) and practice (patents). We captured the trend of IoT publications and patents and reviewed the recent and heterogenous literature on IoT in healthcare. Several key information can be drawn from this study. Firstly, the issue is extremely recent as only in the last six years there has been significant scientific and patent production. Furthermore, we showed the contexts where industry and academic knowledge about IoT flourishes and which institutions or organizations play a leading role in developing that knowledge. Health IoT is currently a global issue for research, while it is geographically confined to patents. Most Health IoT patents belong to private sector companies, while public research organizations seem to play an important role in the development of IoT research. As a policy implication, collaborations between industry and academy should therefore be strengthened.

Secondly, the trend topic analysis added a new and unexplored dimension. Comparing the topics covered in entrepreneurial and academic domains, we understood not only the thematic differences, but also the time asymmetry between the two fronts. Health IoT practice and research are misaligned by a lag in themes.

Thirdly, the analysis of the publication thematic evolution allowed to understand what are the research themes and/or the topic changes, contributing to the research front growth. We observed the development of specific areas over time, such as aged, female, medical informatics, identifying the shift rationale.

The contribution of our study can be outlined as follows. First of all, we used scientometric methods that make the results reproducible and verifiable. Second, the joint analysis of the academic and industry fronts allowed to understand their role within the whole IoT knowledge economy. The results of our analysis, which combines theory and practice, can be useful to scholars engaged in this field of research, and at the same time to entrepreneurs willing to start new projects on IoT applications in healthcare. Although recent literature has analyzed the possibilities and limitations of IoT in healthcare, there is still a lack of interconnection with the world of practice that fails to detect the real progress of some IoT innovations. There have been limited investigations into this relationship so far. Typically, the two front are analyzed separately. In our study using both scientific articles and patents, we were able to verify the trend and degree of alignment between research and practice. In both analyses, we used keywords to analyze the research and practice fronts.

Based on the results of this paper, future studies may also consider other sources of equally valid technological information such as grants or altmetrics. This study paves also the way to an investigation on the niche thematic nodes to see how they can become more central and therefore significant to research, or on emerging thematic nodes and analyze their impact on the industrial sector. Finally, future studies could jointly represent the research front and the practice front through a two-dimensional matrix. Thus, we could understand what are the elements in the entrepreneurial development phase that are also closely followed by academic interest. Although in recent years entrepreneurs have already paid attention to some issues addressed by the academic front, it is foreseeable that greater integration between the two fronts will push entrepreneurs to reduce the gap regarding IoT issues in the health sector.

Funding

This work has been partially financed by the research project "Leading Change in Academic Medical Centers", funded by the competitive call for projects V:ALERE 2019, Università della Campania Luigi Vanvitelli. This project provides insights and evidences to support the Italian Healthcare System and Academic Medical Centers decision-makers.

CRediT authorship contribution statement

Alessandra Belfiore: Data curation, Formal analysis, Roles/Writing - original draft; **Cuccurullo Corrado**: Conceptualization, Supervision, Validation, Writing - review & editing. **Massimo Aria**: Conceptualization, Methodology, Software.

Declaration of competing interest

None.

Data availability

Data will be made available on request.

Acknowledgments

The authors would like to thank all the reviewers for their helpful comments and Angelo Salatino, PhD for his valuable hints.

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