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Research Article

Internet of Things (IoT) Applications in Hospitals: A Systematic Review

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Abstract

Context: The internet of things (IoT) is a system of wireless, interconnected and digital devices that can collect and store data in a network without needing to establish human-to-human or human-to-computer interactions.

Objectives: Due to the importance of adopting up-to-date technologies in hospitals and health centers, this systematic review aimed to explore all aspects of the IoT applicable in hospitals.

Methods: The present study was a systematic review conducted in 4 August 2021 according to PRISMA guidelines. The internet searches were performed to access three scientific databases of PubMed, Scopus, and ISI Web of Science using a combination of keywords, such as the IoT and hospital. Finally, the required data were extracted from original research articles investigating the IoT application in hospitals and were entered into EndNote X8 software. Quality assessment of the studies was carried out by two researchers independently.

Results: A total of 18 articles were included in the study. The application of IoT had been introduced by 13 articles as an effective method in reducing and controlling dust levels as well as improving the quality of health in wards. Moreover, the possibility of using and installing IoT systems on mobile phones as well as their application for monitoring health improvement had been investigated by two articles. The advantages of using the IoT to save time and keep users' information confidential had also been discussed by some other reviewed articles.

Conclusions: It was concluded that the application of IoT system in hospitals increased the quality of healthcare and improved the patient satisfaction. It was also found that adopting IoT technology may have been extremely effective in controlling various hospital infections. Moreover, this technology was detected to have the true potential for improving the security of devices and databases in the hospital. Overall, the application of IoT was confirmed to increase the efficiency of hospitals and health centers.

Keywords: IoT; Hospital; Healthcare

1. Context

The emergence of digital technologies and the invention of ingenious devices have significantly affected the world and quality of human life. Internet of things (IoT) resulting from the evolution of internet technology, among other things, is a new solution for establishing the telecommunication between objects (1, 2). IoT is a system of wireless, interconnected, and digital devices that can collect and store data in a network without the need for human-to-human or human-to-computer interactions. By the 2020s, more than 21 billion devices were connected to the Internet worldwide, which is five times greater than the number of devices connected to the Internet between 2016 and 2020 (3). Moreover, IoT has obtained a special position in the health sector and has shown to have a wide range of applications (4). However, IoT applications have not been prioritized in this area yet, and it seems that adopting IoT technology in the healthcare sector requires defining and prioritizing the applied areas. In other words, prioritization is a prerequisite for using IoT technology in the health sector, which has the greatest potential for undergoing sustainable development of this sector (5).

IoT has been determined to play a significant predictive role in improving hospital health and organizational performance of hospitals due to its ability to collect patients' vital signs and cumulate specific parameters related to chronic and common diseases on a continuous and periodic basis, follow-up and monitor, offer remote services, perform information management, provide the users with intelligent content, as well as facilitate inter-organizational integration and environmental activities (6-10). The convergence of medicine and information

technology, such as medical informatics and healthcare, has also helped reduce the costs and inefficiency and save many lives on a daily basis (11).

Tavakoli et al. indicated that the application of IoT in the medical sector was one of the most important technological methods for enhancing the performance of medical centers such as hospitals and promoting social justice regarding healthcare system (4).

From the perspective of healthcare, any devices used to monitor the patients or collect, share, and analyze patients' data fall into the category of IoT (4, 12). The increase in healthcare costs as well as the patients' inability to make face-to-face visits are among the main incentives encouraging the public to pay more attention to using electronic health services (13). In the current situation where majority of the patients don't have timely access to healthcare services, using IoT in hospitals not only prevents patients from attending the hospital but also facilitates monitoring the patients' conditions (blood pressure, blood glucose, etc.) during specific periods (daily, monthly, etc.). Furthermore, the timely provision of these services may affect and save millions of lives (14). This technology has numerous benefits, including the prevention of diseases, timely and rapid diagnosis of disorders, reduction of medical costs, etc. (15).

When dealing with viral epidemics, such as coronavirus disease 2019 (COVID-19), IoT services facilitates treating patients remotely (e.g., examination and prescription of medication), identifying patients with or suspected of having COVID-19, avoiding the traffic of vehicle transportation provided for maintaining general health, monitoring individuals' body temperature and other vital signs on an instantaneous basis and sending related data to disease monitoring centers, monitoring patients' conditions, disseminating instantaneous information about diseases (e.g., COVID-19), decreasing hospital visits, improving access of citizens to health services, as well as creating a map of high-risk and contaminated areas in the region, city, province, and country, etc. (1, 16).

Nasiri et al. explored the mechanisms of IoT security and privacy in the healthcare and non-healthcare industries and, due to the infancy of IoT technology in the health care industry and its higher sensitivity of security compared to other industries, were able to provide the researchers, managers, and information security professionals with extensive insights into methods of overcoming threats and attacks and developing a secure IoT architecture (17). Moreover, Fele Kari recognized the large amount of obtained data and the lack of confidentiality of information as the dimensions of challenges faced when applying IoT to disabled people (18). Due to the importance of this issue in health field, the present study aimed to systematically review all aspects of the IoT applicable in hospitals.

2. Evidence Acquisition

2.1. Information Sources and Search Strategy

This study, a systematic review conducted based on the PRISMA guideline (19), largely aimed to apply the IoT in hospitals. To this end, PubMed, Scopus, and Web of Science databases were searched in order to retrieve the required articles. It should be noted that the database search in the given scientific webs was performed according to the search strategy presented in Table 1 and based on the PRISMA model (20).

Table 1. Search Strategy of Sources in Scientific Databases

Time Limitation	**Till 2 August 2021**
Language Limitation	English
Database	Web of science, Scopus, PubMed
Web of Science	TOPIC: (iot) OR TOPIC: ("internet of things") AND TOPIC: ("hospitals") OR TOPIC: ("hospital")
Scopus	(TITLE-ABS-KEY (iot) OR TITLE-ABS-KEY ("internet of things") AND TITLE-ABS-KEY ("hospitals") OR TITLE-ABS-KEY ("hospital"))
PubMed	(((iot) OR ("internet of things")) AND ("hospitals")) OR ("hospital")))

2.2. Inclusion Criteria

Original research articles investigating the impact of IoT in hospitals and published until 4 August 2021 were included in the study.

2.3. Exclusion Criteria

The articles published in languages other than English, other types of articles, including review articles, short articles, letters to the editor and case reports, as well as those articles whose full texts were not available were all excluded from this study.

2.4. Study Selection and Data Extraction

After selecting the articles based on the inclusion and exclusion criteria, the data collection was performed using a data extraction form designed according to the objectives of the study. The data extraction form consisted of six parts including information about the first author's name and year of publication, the country in which the study had been carried out, objectives of the study, type of the study, IoT application, and conclusion. Then the data were analyzed adopting the content analysis method. All articles were entered into EndNote X8 software after their retrieval.

2.5. Qualitative Assessment

The titles, abstracts, and full texts of the articles were independently reviewed by two researchers and, in the case of discrepancies, the articles were referred to another researcher.

3. Results

3.1. Summary of Characteristics of Studies

In an initial review of databases, a total of 3858 articles were retrieved and entered into a reference management software called EndNote. After removing the duplicate and irrelevant items based on the evaluation of the titles, abstracts and full texts, 18 articles were selected. The processes of article selection are shown in Figure 1.

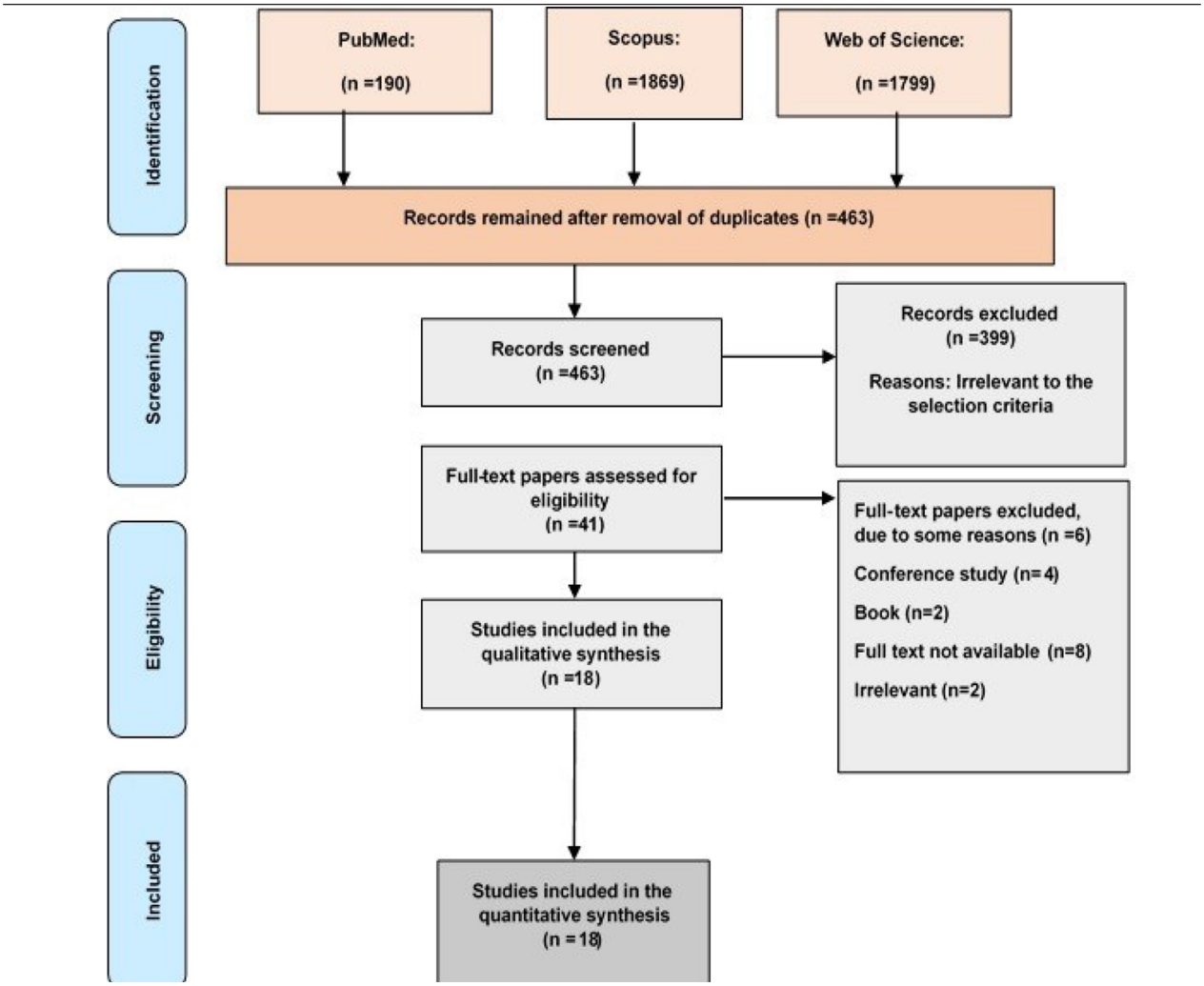

Figure 1. The article selection processes

The distribution of research types of 18 articles is presented in Table 2.

Table 2. Distribution of Research Types

Research Type	Number of Articles
Research and Development	3
Applied Research	4
Quantitative-Prospective	5
Qualitative-Descriptive	2
Qualitative-Observational	2
Descriptive-Analytical	1
Pilot Study	1

3.2. Study Location

The distribution of study locations where 18 articles had been carried out is shown in Table 3.

Table 3. Distribution of Study Locations

Country	Number of Articles
Japan	2
Iran	2
South Korea	2
Brazil	2
Colombia	1
India	1
Ireland	1
Ecuador	1
Turkey	1
Indonesia	1
Tunisia	1
Czech Republic	1
USA	1

3.3. Internet of Things (IoT) Applications in Hospitals

The positive impact of the application of IoT systems on reducing hospital infections, saving time, and improving the quality of health services had been examined in 3, 4, and 2 articles, respectively.

Four studies had investigated the availability of medical information, and one article had studied the confidentiality of this data. In addition, the application of IoT systems in positioning by using related algorithms and two parameters named RSSI (i.e., the measured power) and Tx-power (the transmitted power) through the ratio between them were the subjects of study in one of the articles. Moreover, the issue of patient safety adopting IoT system had been explored in two articles, and the application of an IoT technology called UWB (ultra-wideband) had been recommended by one article in order to improve the interaction between physicians and patients (Table 4).

Table 4. Results of Reviewing the Articles Included in the Study

Author and Publication Year	Country	Objectives	Research Type	IoT Applications	Conclusion
Gonzalez-Palacio, 2018 (21)	Colombia	Provision of a method to improve the measurement of water vapor quality using the principles of thermodynamics and heat transfer in a hospital autoclave by employing IoT	Research and development	Employing IoT in designing autoclave device; All the calculations were performed in a Single Board Computer connected to an IoT platform for logging data, supervising pseudo-real-time, and using statistical tools to inference or predict	The effectiveness of using the IoT platform in minimizing errors and inefficiencies in sterilizing microbes with water vapor
Hanada, 2018 (22)	Japan	Investigating the current state of the IoT in a medical setting focusing on the electromagnetic environment	Qualitative-descriptive	The application of the IoT in the medical environment, with a focus on the electromagnetic environment	Employing the IoT system led to more efficient use of times of hospital staff. Moreover, staff were able to use the saved time to improve the hospital environment and enhance patient care, ultimately leading to an increased efficiency.

Akbarzadeh, 2021 (23)	Iran	Design and development of smart hospitals using IoT systems in the COVID-19 pandemic	Applied research	Using multiple IoT technologies to build a platform for performing active management of public services and healthcare in hospitals	Implementing BLE-based smart hospitals was possible due to low energy consumption and low implementation costs. According to the collected data, BLE (Bluetooth Low Energy) was suitable for simple positioning systems
Bevish Jinila, 2020 (24)	India	Provision of a framework for monitoring health in hospitals by taking into account some factors, such as dust level, air quality, and cleanliness	Research and development	Health monitoring in hospitals by placing sensors in prime points, such as door handles, etc.The data collected from all these sources were analyzed by the central controller, a report was created based on the decision-making process, and the personnel was alerted.	Adopting IoT technology for controlling health in hospitals effectively controlled dust levels and protected the individuals from hospital infections. The proposed approach improved efficiency and profitability of risk management strategies.
Joseph, 2019 (25)	-	Designing an Intravenous Drip Monitoring System (IV System)	Research and development	Hardware part and software sensors, data retrieval, and storage to automate droplet monitoring systems; IoT devices regularly collected data from the users and environment, and send them to the application via Bluetooth media. Some data, such as heart rate, blood pressure, temperature, and fluid level were monitored in real time. The sensor read the level of values and compared them with threshold or preset value, and the nurses or medical staffs were alerted if the value was less than that of threshold.	This system reduced the adverse effects of intravenous drip injection in hospitals.

Catherwood, 2018 (26)	Ireland	Investigating the performance of ultra-wideband as an IoT technology in hospital wards	Quantitative-prospective	Using UWB (ultra-wideband) model in hospital wards	Presenting a UWB model as an active IoT technology in hospital environments for wearable smart devices for physician to evaluate different conditions of patients
Fischer, 2020 (27)	Brazil	Evaluation of IoT in smart hospitals in terms of human resource management and patients' waiting times	Qualitative-observational	In order for exchanging information, determining the most demanding times of rooms, as well as establishing EIHealth, the RFID technology was adopted for the staff, and each patient was assigned a wristband with RFID capability.	The proposed EIHealth model, which used identification labels for patients during their stay, was able to reduce patients' waiting times for healthcare. Regarding human management, ElHealth produced some notifications for human resources; however, the effective movement of staff in the hospital environment depended on their individual decisions to follow the recommended guidelines.
Nandyala, 2016 (28)	South Korea	Proposing an architecture for IoT-based healthcare monitoring with the motivation and benefits of Cloud to Fog (C2F) computing	Quantitative-prospective	Minimization of delays in data analysis in the hospital, and etc. The proposed architecture used Fog computing, the appropriate platform for a number of critical IoT services and applications in U-healthcare monitoring.	The C2F architecture worked effectively to monitor healthcare in hospitals and smart homes with faster processing and less latency.

Mohaghar, 2019 (29)	Iran	Conceptual modeling of IoT implementation in supply chains of hospitals	Qualitative-descriptive	Health, safety, and easy access to medical and hospital services promoted continuous care and quick support. Meta-synthesis method was used as a suitable approach to achieve a comprehensive combination of factors constituting the IoT implementation model in hospital supply chains.	The IoT implementation model in hospitals, analysis of results before and after the implementation of IoT technology, and measurement of supply chain indicators, such as performance, stability, and elasticity, etc. were able to greatly facilitate implementation of this technology. This study suggested that the researchers should study IoT modeling in other areas of the health industry, such as producing and distributing drugs, manufacturing medical equipment, etc.
Uslu, 2020 (30)	Turkey	Exploring the benefits of the IoT in smart hospitals	Applied research	IoT technology played an important role in connecting devices and their simultaneous operation. IoT allowed systems to work together as infrastructures using sensors, connection methods, Internet protocols, databases, as well as cloud and analytical computations. In this study, the factors required to optimize IoT-based design of smart hospital were analyzed based on five integrated IoT layers. Layer 1) Sensor layer (data collection technology), Layer 2) Network layer: This layer manages the data transfer to remote servers and connects systems and platforms. Layer 3) Remote server layer: Represents remote computing technology of IoT system, Layer 4) Knowledge layer: This layer includes intelligent decision-making and analysis module of IoT systems in which knowledge processing was performed, Layer 5) Application layer: This layer includes service platforms used by the stakeholders of each system.	IoT technology provided excellent opportunities for intelligent healthcare systems to develop and manage wearable technologies, share information at the needed time, monitor patients and applications.

Nursuwars, 2019 (31)	Indonesia	Development of an RFID-based nurse call system using the IoT concept	Applied research	A nurse-call system that allowed patients in the health-care unit to remotely call nurses or other healthcare staff for help when required.	A nurse-call system is an important tool for any hospital. The nurse-call system has been designed not only to facilitate contacting the nurse but also to record the message when a patient calls a nurse and detrmine the nurse responding to each call. Moreover, the quality of the information provided in this method can be evaluated by hospital officials according to the number of calls, and the time spent by the nurse for each call.
Ben Ida, 2020 (32)	Tunisia	Provision of a self-adaptative early warning score system in smart hospital context	Quantitative-prospective	Smart medical devices were major parts of the smart hospital environment. Their main purpose was to collect data on the patient's vital signs or other physiological conditions. These automated systems reduced errors in manual systems of early alerts and facilitate nurses' performances, such as collecting and permanently storing patients' vital signs.	The system provided a manual and self-adaptive configuration of the monitoring process of vital signs depending on the variety of patients' health status and decisions of medical staff.
Urbanczyk, 2016 (33)	Czech Republic	Development of a database for the hospital emergency department based on the IoT	Prospective	The IoT improved the analysis and processing of data and results, as well as eliminated and reduced the problems of paper forms (e.g., illegibility of forms or human errors that may be seen in paper forms). In order to develop an IoT-based database for emergency department, the following were investigated: analysis of hospital emergency department, introduction of an appropriate identifier for the hospital environment, introduction of ID scanning technology, analysis of sequence of emergency department, development of WiFi network system and card ID	The electronic record of intensive care had great potential for creating new and effective medical records, which facilitated further analysis of the results using the IoT when the data were in a structured form.

Yamashita, 2019 (34)	Japan	Control of hospital infections using the IoT	Quantitative-prospective	Given the current state of hand hygiene, using IoT's benefits facilitated controlling infection and creating a safer medical environment. The development of IoT gateway for achieving data and location information, including alerts of medical devices and various sensors	Using IoT was effective in controlling infection and hand hygiene.
Espinoza, 2020 (35)	Ecuador	Evaluating the IoT security in public and private hospitals	Applied research	Collecting comprehensive information, transferring secure information, processing data, and converting medical system data based on medical knowledge. Establishing an electrocardiographic device to provide services and monitor patient health in the IoT environment. The data were stored in the cloud of a provider. Also, the provider applied HIPAA rules for the security of health data.	The cybersecurity standards applied to IoT design for designing a public or private hospital provided trust in information assets, confidentiality, integrity, and availability of information.
Kang, 2019 (36)	South Korea	Assessing the demand for various services based on the IoT from the perspective of nurses	Descriptive-analytical	Adopting IoT improved the quality of patient care, reduced the need for nurses, and decreased the duration of hospitalization, etc.	In sum, employing IoT technology by hospitals improved the patient's level of safety and the efficiency of the medical staff.
Fischer, 2019 (37)	Brazil	Applying ElHealth to control patients' use of hospital rooms and accommodate rooms to patients' demands	Qualitative-observational	Using IoT technology to control patients' use of hospital rooms. Installation of sensors around the hospital as well as at all entrances and exits to identify patients	This model was effective in reducing patients' waiting time.
Balaguera, 2017 (38)	USA	Applying IoT technology to evaluate the speed of nurses' response to getting patients out of bed in hospitals caring for patients with acute conditions	Pilot study	IoT enhanced the level of patient care and safety. Sensor technology, microcontrollers, IoT, and computer or user interface were used. Sensor technology was applied to create appropriate methods for identifying digital and analog sensors. IoT was also employed to exchange data between devices and users.	IoT system had the potential to reduce the risk of a patient's falling out of bed.

4. Discussion

In the present study, 21 cases of IoT applications in the hospital were identified as the result of reviewing the articles. The results indicated that this frequently used and extremely effective technology had the true potential to reduce hospital infections. Designing systems capable of monitoring air quality and dust levels on the hospital grounds was one of the applications identified by Bevish Jinilia et al. (24). Using a mechanism based on this technology was a method introduced by another study to control hand hygiene and infection rate in the hospital environment (33). According to our review results, moreover, IoT was a technology capable of saving time and improving staff performance. As discussed by Hanada et al., this technology helped hospital staff to use their time more efficiently. In this regard, hospital staff used the saved time to provide the patients with further care (22). In addition, using ElHealth model was discovered capable of reducing the patients' waiting time for healthcare (27). Our review results also showed that adopting IoT technology increased the quality of hospital services and, subsequently, improved the patient satisfaction with the received services. Therefore, it was suggested that a system should be designed and provided based on IoT technology to improve the quality of patient care. Furthermore, Aguirre et al. had proposed a device capable of improving the level of medical services by applying a Wi-Fi network, providing accurate and sufficient information about the patient's history and, in case of emergency, enhancing the provision of services for patients with maximum speed and precision. Therefore, it was suggested that an Android application should be designed using IoT to develop electronic health systems capable of representing patient information (39). The IoT technology provided excellent opportunities for intelligent healthcare systems to share information when desired and to monitor the patients (30). Other applications of this technology in the hospital included nurse call systems, which worked based on the IoT concept, and a menu of the types of calls listed based on the patient's needs, enabling the nurses to provide the necessary services more quickly (31). The IoT technology has been proven extremely practical and effective in the field of confidentiality, integrity, trust in information assets, and availability of information (35). Moreover, some IoT-based sensors have been designed that are capable of monitoring the patient's vital signs and informing the nurses about the their health status continuously and regularly and, therefore, facilitating the provision of care services for patients and reducing nurses' workload (40). IoT was also found to improve patients' safety. For instance, Balaguera et al. investigated an IoT-based system which was capable of reducing the risk of patients falling out of bed (38). In sum, it was determined that using IoT technology in different wards of hospitals may have improved hospitals' overall performance regarding the provision of medical services for patients and may have had other subsequent benefits.

4.1. Conclusion

It was concluded that using IoT systems in hospitals increased the quality of healthcare and improved patient satisfaction. It was also found that adopting IoT technology may have been effective in controlling various hospital infections. Furthermore, this technology was determined to improve the security of devices and databases in hospitals. Overall, IoT application was detected to enhance the efficiency of hospitals and health centers. Due to the prevalence of epidemics (e.g., COVID-19), it was recommended that intelligent medical technologies, including the IoT, should be employed in order to strengthen the healthcare system by preventing the contact with the carriers. Due to the infancy of this technology in the health field and a higher sensitivity of its security compared to that of other technologies, moreover, it was suggested that necessary measures should be taken in order to address the threats and develop a secure IoT architecture.

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