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REVIEW

A Systematic Literature Review on Trustworthiness for Applications Used in eHealth Environments

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Context: The technological advancement of the Internet of Things (IoT) creates opportunities in various social sectors. Patients in clinics or home care have their comfort and safety enhanced with remote monitoring, sensors and applications that control and transfer patient data. These applications must be trustworthy, since they deal with sensitive data.

Purpose: The purpose of this work is to identify gaps in trustworthiness, availability, effectiveness, security and other attributes. Also, to highlight challenges and opportunities for research and give guidance on choosing the right technology or application based on the resources available to support patients and doctors, protocol of communication and maturity level of these technologies.

Methodology: This work presents a systematic review of the literature following four steps: Definition of the Research Questions, Conduct Search, Screening of Papers, and Data Extraction and Mapping Process.

Results: Based on the articles studied, it was possible to answer important questions about eHealth applications. The results highlight how eHealth applications can enhance patient care by monitoring health data and supporting doctors' decision-making with a reasonable level of trustworthiness. Additionally, the results demonstrate how applications can notify external caregivers in emergencies and assist in diagnosis and treatment of illnesses. However, these applications still face problems related to sensor lifetime, medical data sharing, interoperability and lack of standardization. Finally, we suggest a literature mapping to support the choice of technologies based on resources available, communication protocol and technological maturity.

Conclusion: This work carries out a systematic literature review to discuss state-of-the-art eHealth applications and gather new information of current research. In this process it was possible to show how these applications work, map out their main technological characteristics to assist the decision-making process for future works and uncover eHealth applications' strengths, future perspectives and challenges, specifically related to the high level of trustworthiness necessary.

Keywords: internet of things, IoT, remote monitoring, healthcare, decision making

Introduction

An important and current use of IoT applications is in eHealth. In an eHealth environment, IoT devices can monitor patients in their residence and transmit information between devices and/or to an external caregiver (whether a doctor, nurse or automated system).

Often, users involved in telemedicine (either the patient or caregiver) use mobile applications to consult the data or to control devices in these environments. Medical consultations can be carried out via telemedicine with a good level of satisfaction on both sides[1] and even perioperative monitoring can be carried out with the new technologies developed.[2]

IoT devices collect, process and transmit data from an eHealth environment. Here is the focus of the research problem, as this type of data is sensitive and needs to be precise, coherent and up to date for decision making in a case of an emergency.[3,4] One of the main limitations of these applications is access to inaccurate patient information, through

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different eHealth applications. IoT applications are limited and cost-inefficient in terms of security, transmission and interconnectivity.[5]

There are several applications related to remote patient care available in the literature, but it is not possible to guarantee their trustworthiness. This qualifies as a research topic, precisely because these applications are working with sensitive data, which are directly related to patients' health and well-being. The scope for the work is the comprehensive analysis of design and methodology flaws regarding eHealth solutions.

This work does a systematic review of the literature to answer six defined questions. The contributions of this paper are: (i) organization of the research ideas in clear topics, (ii) discussion of methodology weakness found in some works, (iii) listing of open challenges for the field, (iv) mapping the main technological characteristics to assist the decision-making process for future works. These four points are valuable suggestions for future research and qualify as novelty for the literature.

The remainder of this work is organized as: Research Methodology, Results, Discussion and Conclusion.

Research Methodology

This Systematic Literature Review (SLR) aims to understand the state-of-the art of eHealth applications. The method used in this article is based on Petersen[6] and conducts the following steps: (i) Definition of the Research Questions, (ii) Conduct Search, (iii) Screening of Papers, and (iv) Data Extraction and Mapping Process. Figure 1 shows the Research Methodology used with the steps detailed.

Definition of the Research Questions

The SLR begins with the definition of the research questions. These questions guide the search for relevant, up-to-date work. Based on the scenario defined in the Introduction the following questions are defined:

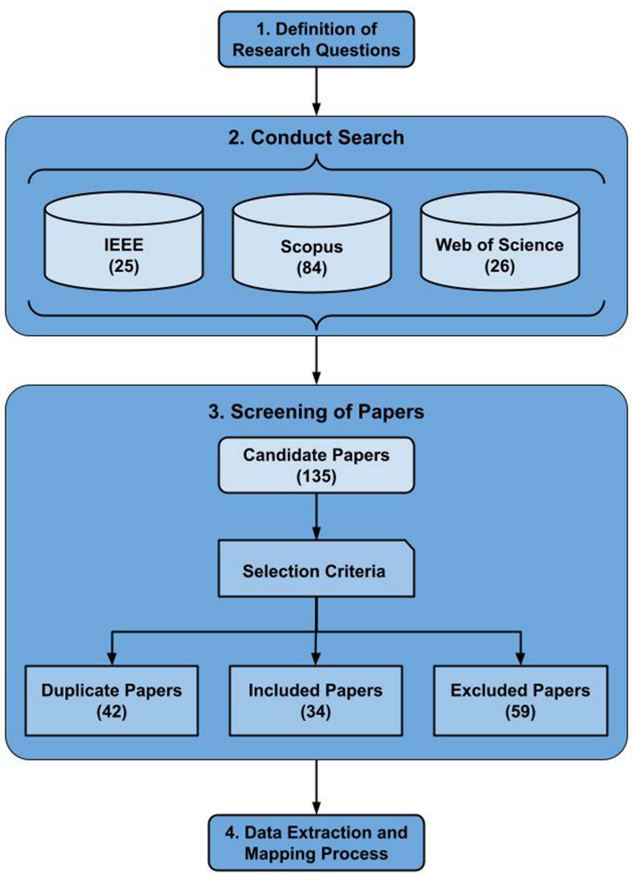

Figure 1 Search protocol model adopted.

1. RQ1: How do applications that handle information from eHealth systems work?
2. RQ2: What information can one monitor through these applications?
3. RQ3: Are these applications trustworthy?
4. RQ4: How well can a patient be monitored with these applications?
5. RQ5: How would the doctor be notified in the event of an emergency?
6. RQ6: What are the advantages and disadvantages of these applications?

Answering the proposed questions it is possible to understand the current scenario of eHealth applications, the positives and negatives points and propose future works. After the analysis of the selected works, the questions are answered in Discussion.

Conduct Search

To identify candidate papers, the SLR search protocol scope is defined. The first step in conducting the search is to establish the search string. Correct word selection is critical to the results needed and to remove false positives. The following search string is defined based on Kitchenham.[7]

("IoT" OR "Internet of Things" OR "Smart Devices") AND ("eHealth" OR "Health" OR "Healthcare" OR "Telehealth") AND ("Application") AND ("Monitoring" OR "Sensing" OR "Detection") AND ("Wearable" OR "Ubiquitous" OR "Biosensor") AND ("Zigbee" OR "Lora" OR "5G" OR "WIFI")

Screening of Papers

In addition to the keywords, filters are used according to the inclusion criteria, such as the year of publication and language. The following databases are consulted: Institute of Electrical and Electronics Engineers (IEEE) IEEExplore digital library (https://ieeexplore.ieee.org/), the Elsevier Scopus (https://www.elsevier.com/en-us/solutions/scopus) and the ISI Web of Science (https://clarivate.com/webofsciencegroup/).

The search returned 135 papers (IEEE: 25 articles, Scopus: 84 articles and Web of Science: 26). Then, the inclusion and exclusion criteria described in Table 1 and Table 2 are applied to these 135 articles, which selected 34 articles for the full reading.

Table 1 Inclusion Criteria (IC)

Criteria	Description
IC-01	The article must contain the searched keywords.
IC-02	The article must feature a eHealth-related application.
IC-03	The article must present the development of a software, application or modeling.

Abbreviation: IC, Inclusion criteria.

Table 2 Exclusion Criteria (EC)

Criteria	Description
EC-01	Be in a language other than English.
EC-02	It is not an article.
EC-03	The article does not have an eHealth-related application.
EC-04	The article does not contain the searched keywords.
EC-05	Duplicate articles.

Abbreviation: EC, Exclusion criteria.

When it comes to EC-02 - It is not an article, in the context of this research, only scientific articles published in journals indexed by the search engines SCOPUS, IEEE, and Web of Science were considered. In addition to scientific articles published in journals, these search engines also index the following types of documents (which were not considered in the context of this research):

- SCOPUS: Books, Technical Reports, and Patents;
- IEEE: Books, eBooks, and IEEE Standards;
- Web of Science: Reviews, Patents, Books and book chapters, Technical reports, Scientific news, Theses, and Dissertations.

Data Extraction and Mapping Process

After selecting the articles to compose this work, data extraction aims to collect relevant information to answer the research questions defined in the protocol of this systematic literature review. After read each paper completely, the key items were extracted:

- Title;
- Year of publication;
- Keywords;
- Addressed Issue;
- Main concepts covered (security, usability and etc.);
- Main technologies used;
- Research questions:
  - RQ1: How do applications that handle information from eHealth systems work?
  - RQ2: What information can one monitor through these applications?
  - RQ3: Are these applications trustworthy?
  - RQ4: How well can a patient be monitored with these applications?
  - RQ5: How would the doctor be notified in the event of an emergency?
  - RQ6: What are the advantages and disadvantages of these applications?
- If the technology was validated through laboratory/simulation tests or through industrial application.

Figure 2 shows the systematic mapping resulting from reading and extracting data from the selected articles. Systematic mapping allows the choice of eHealth technology based on the resources available in each one, their level of maturity and the communication protocol used.

Results

Figure 3 shows the percentage of papers found in each of the databases and Figure 4 shows the amount of work per year. The remainder of this section presents the main topics found in the articles, divided by the main communication protocol used.

ZigBee

The papers characterize ZigBee protocol as a low frequency transmission protocol, that is suitable for applications where a sensor network may contain many devices, and energy consumption is a relevant point for the systems architecture. The main concepts found in the articles in this section are trustworthiness, security, accuracy and scalability. It is worth pointing out that authors opted for the protocol that guarantees energy efficiency to carry out the monitoring, but the authors still have concerns about the manipulation and security of the generated data.[8–13]

LoRa

The major feature described by the papers about the Long Range (LoRa) protocol is its coverage area, without having an excessive consumption of energy. In the articles presented in this section, the key terms are reliability, cost effectiveness, independence, security and performance. The remote monitoring of the patient or the environment still brings some

	RESOURCES			TECHNOLOGY MATURITY	
Main Protocol used	Capable of monitoring patient data?	Capable of monitoring environmental data?	Allow emergency notifications?	Tested in the Laboratory?	Tested in the Industry (Hospital)?
ZigBee	[8], [9], [10], [11], [12], [13]	---	[09], [11], [12].	[08], [11], [12].	---
LoRa	[14], [15], [16], [17], [18], [19], [20], [21], [22].	[15], [16], [17], [19], [20], [22].	[14], [15], [16], [17], [18], [19], [20].	[14], [15], [16], [17], [18], [19], [20], [21], [22].	[14], [17], [20].
5G	[23], [25], [26].	[25]	---	[23], [24], [25], [26]	[23]
WiFi	[28], [29], [30], [31], [32], [33], [35], [36], [37], [38], [39], [40], [41].	[33], [37].	[29], [33], [37], [38], [40], [41].	[27], [28], [30], [31], [33], [34], [35], [36], [39], [40], [41].	[35]

Figure 2 Systematic mapping.

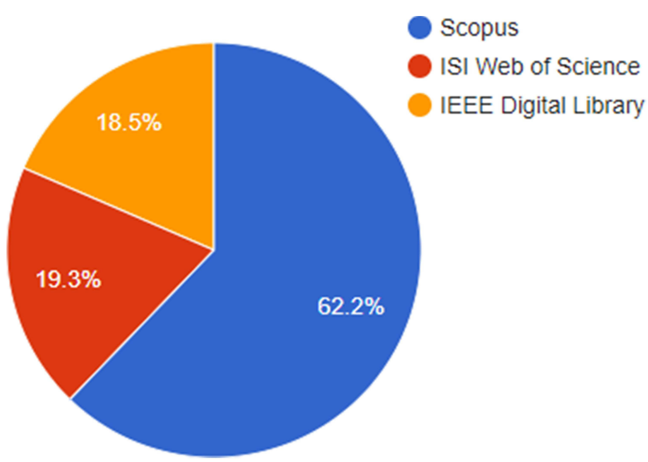

Figure 3 Papers per database.

uncertainties, since energy efficiency is not enough to guarantee the effectiveness of the system, it is also necessary a good relationship between performance and safety on long range monitoring.[14–22]

5G

5G technology promises a high data transmission rate and at high speed and with low latency. It is possible to see this characteristic in the articles listed, and the key concepts of their applications are performance, response time and

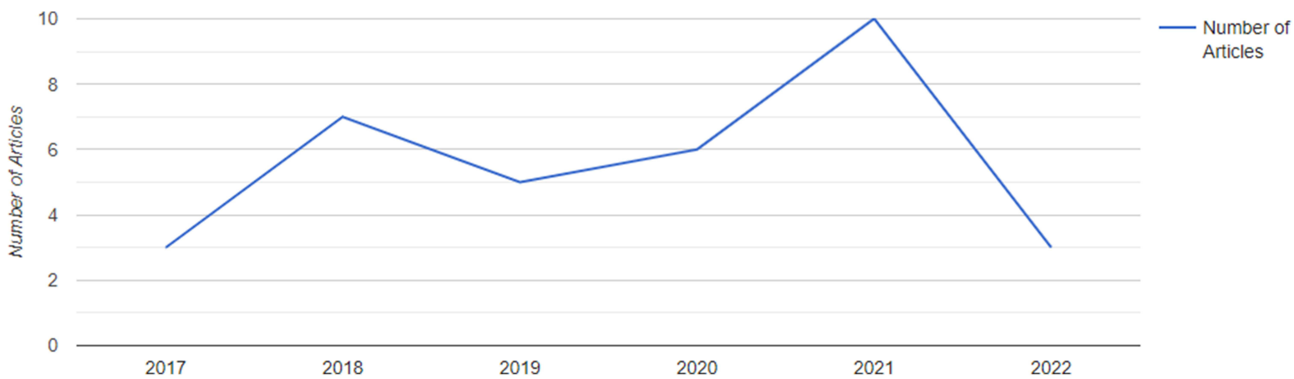

Figure 4 Papers per year.

effectiveness. However, there is a recurring concern about the energy efficiency of the systems. The higher the transmission speed and the amount of data transmitted, the higher the energy cost of the application, and this is still a problem to be solved. The authors propose different strategies to improve this correlation, but there is still much to be explored within these works.[23–26]

WiFi

A great variability of works using Wireless Fidelity (WI-Fi) was proposed in the papers, generating a broad set of key terms. In this context, it is possible to find trustworthiness, affordability, efficiency, security, accuracy, etc. Despite the significant advances in the area in recent years, which have grown continuously, different obstacles generate concern for authors and need to be overcome. It is possible to see this plurality of concerns in this section, where the authors propose different techniques and applications to solve the respective problems mapped in the papers.[27–41]

Based on the articles studied in this section it is possible to plan the discussion of the results, answering the research questions defined.

Discussion

In this section, the answers to the research questions defined in Research Methodology are discussed.

RQ1: How do applications that handle information from eHealth systems work? Despite the unique individual characteristics of each application studied in Results, there is a standard structure followed by most papers. eHealth environments are usually composed of a set of sensors that monitor and collect patient's data, cloud servers and web and/or mobile applications to control, oversee or present the data. Figure 5 shows an example of systems modeling.

RQ2: What information can one monitor through these applications? Traditional health monitoring systems can monitor different medical data, such as cardiac activity through ECG (electrocardiogram) sensors, blood sugar level, pulse, blood pressure, number of steps, heartbeat, respiration rate, body and ambient temperature, and many others.

Other interesting examples are: Han[21] uses a method based on multi-sensors to detect and understand users' posture. Wu[22] focuses on monitoring the environment the user is in, factors such as carbon monoxide level, carbon dioxide and ultraviolet intensity can directly affect the health of people in the environment. Respiration rate is the key factor monitored to help the diagnosis and treatment of COVID-19 within the context of the pandemic, where personal contact needs to be minimal, as presented by Li.[41] Nataraja[13] proposes an IoT based solution that can be adapted into Lateral Rotation Mattress used for bed-bound patients by embedding sensors to recognize patient discomfort.

eHealth systems can present the health data collected in the monitored environments in different ways, however, the authors agree that the best strategy is between a mobile application or a responsive web application.

RQ3: Are these applications trustworthy? Evaluating the chosen articles one notices that 27 of the 34 works studied presented tests or practical applications of their proposed systems. Unfortunately, the tests usually include only the fundamental concepts (accuracy, safety and efficiency, for example), but not all concepts that makeup an application of this type. Thus, one can evaluate the applications as trustworthy if analyzed only for the key purpose. To become

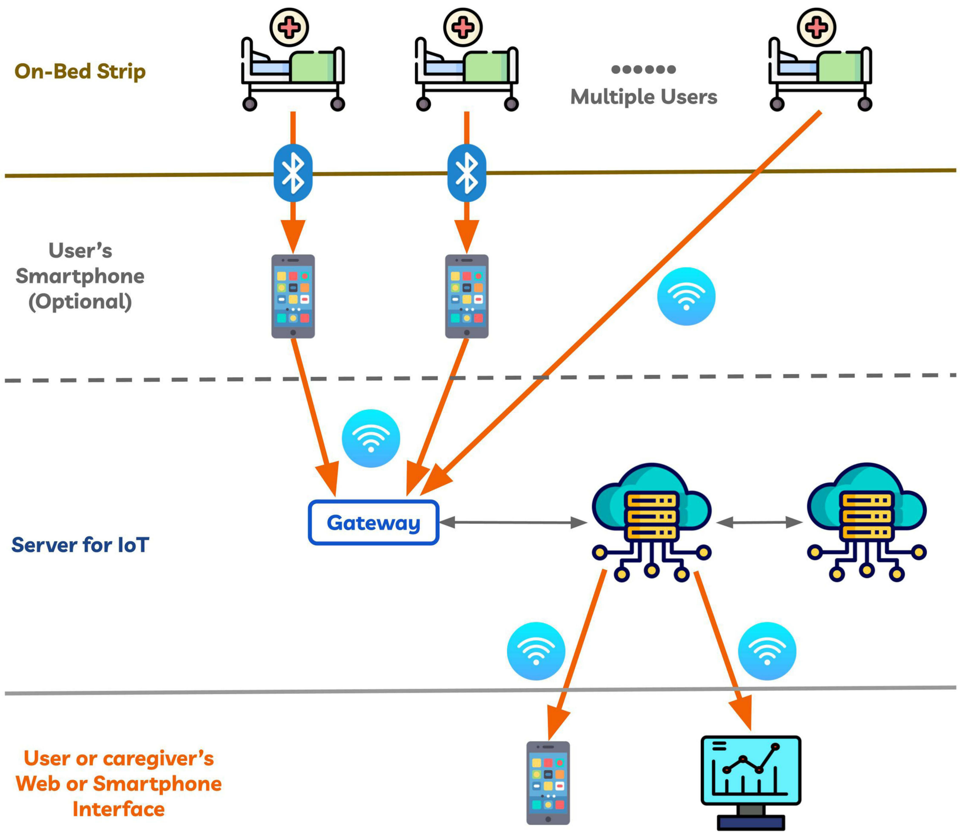

Figure 5 Example of system modeling found in the literature. Overall scheme of remote personal or group monitoring platform.
Notes: Adapted from Choi A, Noh S, Shin H. Internet-based unobtrusive tele-monitoring system for sleep and respiration. *IEEE Access*. 2020;8:76700–76707.[35]

completely trustworthy, tests that go beyond the concepts defined by the authors are necessary, perhaps using frameworks and architectures that cover the entire scope of an application, to demonstrate a functional prototype.

RQ4: How well can a patient be monitored with these applications? Along with the new technologies developed, new options for patient monitoring become accessible. Currently, not only doctors can monitor a patient's health but also other external caregivers (nurses, automated systems, relatives, for example). Among the monitoring solutions presented in this work, there are cases where authors present testing processes concerned with the quality of patient monitoring. Although, in other papers, to measure how well these systems can monitor patients, more testing is necessary. In general, a good monitoring level is found in the presented scenarios.

RQ5: How would the doctor be notified in the event of an emergency? In addition to real-time monitoring, the systems also offer tools to notify caregivers in emergency cases.

Emergency situations, such as sudden cardiac arrest, require immediate emergency medical services. The system proposed by Wu[17] triggers an emergency alarm if the router does not detect a heartbeat within 2 seconds, that means, when the heart rate is below 30 beats per minute (BPM) or cardiac arrest occurs. The maximum response time is the 2s threshold, in addition to the BLE (Bluetooth Low Energy) transmission delay from the sensor node to the local router.

Sood[37] proposes the Sukoon application, which gives the current location: latitude and longitude in case of emergency situations to the necessary user's contacts. Also, the application gives the contacts places to call to, when either the user presses the panic button or the combined values of accelerometer and pulse rate sensor crosses the upper limit threshold. Also, the Global Position System (GPS) coordinates can be sent in case of an emergency. This exemplifies the capacity of emergency notifications of these applications, however, still with limitations. The authors developed the application only for the Android system, and the distance between the hardware and the application cannot be further than 14 meters, which can be an obstacle most times.

The system proposed by Li[41] uses the Grafana visualization to allow the provider to set up alarms when the Respiration Rate passes (RR) certain thresholds. When Grafana detects an “unusual” respiration value, it triggers an alarm in the dashboard, which allows the healthcare provider to visualize the current status of the patient. The framework allows users to visualize both current RR and historical information, which helps the decision-making process. However, the authors design the system to be implemented on specific devices that can use Wi-Fi, which can be a limiting factor for some environments.

RQ6: What are the advantages and disadvantages of these applications? Applications such as those studied in this work offer significant advances related to the care of a patient, and these advances are the major strengths of these applications. For example, in contexts where human contact needs to be minimized, as seen in the COVID-19 pandemic, or other diseases with a high transmission rate, the possibility of remote health monitoring is a powerful tool to avoid the spread of diseases, and ensure the safety of medical staff and other patients.

Often, health systems in different countries have difficulties in dealing with the volume of patients, as in a pandemic context, for example, and tools for remote monitoring can be more accessible solutions for the general population. Implementing those applications needs fewer physical resources, such as hospital facilities and high cost equipment, and these solutions provide patients with more freedom and comfort by allowing them to receive treatment and recover at home.

In addition to monitoring the patient’s health, it is also possible to monitor the surrounding environment. In this way, the system or an external caretaker can take actions to deal with the patient’s health and to improve the environment in which he is. Besides the decision-making process related to the patient’s health and surroundings, the systems also enhance the possibility of speeding up helping a patient in emergency cases.

Finally, another positive point of these tools is related to the possibility of carrying out intelligent diagnosis of diseases in advance.[13,29,39,41] Therefore, it is possible to effectively predict future health needs, monitor conditions in real time, and act imperatively toward urgent needs.

Based on the studied papers, it is possible to directly relate the main negative points of these applications to the limitations they have. For example, the authors directly linked the lifetime of sensors that monitor a patient or environment to the battery of these sensors and that is why some articles seek solutions to reduce energy consumption.

Sensors are devices that have physical limitations. Ensuring that these devices have a sufficiently long lifespan is essential for proper patient monitoring. Even with systems allowing the use of technologies and protocols aimed at low energy cost and the efficiency of the environment, this limitation is still an impediment to the practical application of several systems. This is a challenge faced by any application that seeks to perform remote patient monitoring.

Medical data sharing is another important issue with security and is another point treated by part of the papers. When dealing with information considered sensitive, the loss, interception or alteration of data can have severe consequences for patients. Another important factor is the distance at which a system can monitor the patient without loss of information or response time in emergency cases. Therefore, this also needs to be considered when developing an application of this type.

The correct functioning of the systems depends on the proper use of different sensors, which monitor different aspects of a patient’s health. Interoperability is a requirement of these systems. The systems must be able to understand the data coming from these sensors regardless of the type of information collected, for example, temperature, heart rate, blood sugar, etc. Devices also need to be interoperable, as sensors need to know each other within the sensor network. Several applications cannot use protocols or technologies different from those proposed by the authors. Thus, these systems are limited to specific cases, and replication in other cases may be unfeasible.

Conclusion

Monitoring personal health is an important application of IoT systems. This work carries out a systematic literature review to discuss state-of-The-art of these applications and gather new information of current research. In this process were uncovered eHealth application’s strengths, future perspectives and challenges, specifically related to the high level of trustworthiness necessary.

The developed work shows that it is possible not only to monitor patients and make emergency decisions, but also the prospect to diagnose and prevent diseases using IoT devices and collection data. However, these applications still lack a standardization or set of good practices to guarantee the trustworthiness of use.

Selecting the best architectural and technological strategy for an application is also an important factor. In a health monitoring environment, this is an arduous task, considering the advantages and disadvantages of the different technologies and protocols available. In pursuit of this goal, the present study offered a comprehensive mapping of the protocols used by the authors and the level of technological maturity shown in these works.

Another important factor raised in the work was the COVID-19 pandemic scenario, where these applications are proved even more important, since remote healthcare was a key factor. In a context where health systems around the world can be overwhelmed by the volume of patients, options accessible to the population and that allow them to support it in uncertain times become essential for the future of modern medicine.

The papers evaluated deeply debated issues such as security, energy efficiency, usability, precision and others. In addition, all articles were published in the last six years, showing that these issues are contemporary and relevant to the current context of technology.

Even with all the positive points presented in the articles, there are still gaps for future research. The monitoring distance, for example, is an essential issue in this context. The greater the monitoring distance is, the more difficult it is to guarantee the quality of the system's attributes. IoT applications need to be made for scalability, so increasing the monitoring distance and the number of patients monitored is a key aspect in this scenario. This represents a limitation that many of the studied systems face, and more research is needed to mitigate quality decrease.

Disclosure

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References

1. Bowen SC, Gheewala R, Paez W, Lucke-Wold B, Mitin T, Ciporen JN. Telemedicine visits in an established multidisciplinary central nervous system clinic for radiation oncology and neurosurgery (RADIANS) in a community hospital setting. *Bratisl Lek Listy*. 2021;122(9):680–683. doi:10.4149/BLL_2021_109
2. Lucke-Wold B, Cerillo JL, Becsey AN, Chernicki BP, Root KT. Minimally invasive procedures, perioperative telemedicine, and decreased hospital stays following covid-19 surgical restrictions: spinal surgery. *Arch Med Case Rep Case Study*. 2022;6(5):153.
3. Kumarage H, Khalil I, Alabdulatif A, Tari Z, Yi X. Secure data analytics for cloud-integrated internet of things applications. *IEEE Cloud Compu*. 2016;3(2):46–56. doi:10.1109/MCC.2016.30
4. Khan AA, Laghari AA, Shaikh ZA, Dacko-Pikiewicz Z, Kot S. Internet of things (IoT) security with blockchain technology: a state-of-the-art review. *IEEE Access*. 2022;10:122679–122695. doi:10.1109/ACCESS.2022.3223370
5. Khan AA, Wagan AA, Laghari AA, Gilal AR, Aziz IA, Talpur BA. BIoMT: a state-of-The-art consortium serverless network architecture for healthcare systems using blockchain smart contracts. *IEEE Access*. 2022;10:78887–78898. doi:10.1109/ACCESS.2022.3194195
6. Petersen K, Feldt R, Mujtaba S, Mattsson M. Systematic mapping studies in software engineering. 12th International Conference on Evaluation and Assessment in Software Engineering (EASE); 2008:1–10. doi:10.14236/ewic/EASE2008.8
7. Kitchenham BA, Charters S, Budgen D, et al. Guidelines for performing systematic literature reviews in software engineering. Technical Report EBSE 2007-001, Keele University and Durham University Joint Report; 2007.
8. Prasad D, Chiplunkar NN, Nayak KP. A trusted ubiquitous healthcare monitoring system for hospital environments. *Int J Mob Comput Multimedia Commun*. 2017;8(2):14–26. doi:10.4018/IJMCMC.2017040102
9. Brindha DV, Lokeswari U, Saraswathi B, Vindhya T. An effective cloud based personal emergency response system by providing privacy protection for the medical data. *Int J Eng Technol*. 2018;7(2):261–265. doi:10.14419/ijet.v7i2.33.14165
10. Lakshmi GJ, Ghonge M, Obaid AJ. Cloud based IoT smart healthcare system for remote patient monitoring. *EAI Endorsed Trans Pervasive Health Technol*. 2021;7(28):e4–e4. doi:10.4108/eai.15-7-2021.170296
11. Liu Y, Cui J. Design and Implementation of Human Health Monitoring Platform Based on Internet of Things Technology. IEEE International Conference on Computational Science and Engineering (CSE) and IEEE International Conference on Embedded and Ubiquitous Computing (EUC); 2017;422–425. doi:10.1109/CSE-EUC.2017.266
12. Yi WJ, Wang B, Dos Santos BF, Carvalho EF, Saniie J. Design Flow of Neural Network Application for IoT Based Fall Detection System. IEEE International Conference on Electro/Information Technology (EIT); 2018:0578–0582. doi:10.1109/EIT.2018.8500179
13. Nataraja S, Nataraja P. IoT based application for e-health an improvisation for lateral rotation. 2nd IEEE International Conference on Recent Trends in Electronics, Information and Communication Technology (RTEICT); 2017:1018–1021. doi:10.1109/RTEICT.2017.8256753

14. Huynh QT, Nguyen UD, Tran BQ. A Cloud-Based System for In-Home Fall Detection and Activity Assessment. 7th International Conference on the Development of Biomedical Engineering in Vietnam (BME7); 2020:103–108.
15. Wu F, Wu T, Yuce MR. An internet-of-things (IoT) network system for connected safety and health monitoring applications. *Sensors*. 2019;19(1):21. doi:10.3390/s19010021
16. Wu F, Wu T, Yuce MR. Design and Implementation of a Wearable Sensor Network System for IoT-Connected Safety and Health Applications. IEEE 5th World Forum on Internet of Things (WF-IoT); 2019:87–90. doi:10.1109/WF-IoT.2019.8767280
17. Wu F, Qiu C, Wu T, Yuce MR. Edge-based hybrid system implementation for long-range safety and healthcare IoT applications. *IEEE Inter Things J*. 2021;8(12):9970–9980. doi:10.1109/JIOT.2021.3050445
18. Kharel J, Reda HT, Shin SY. Fog computing-based smart health monitoring system deploying lora wireless communication. *IETE Technical Rev*. 2018;36(1):69–82. doi:10.1080/02564602.2017.1406828
19. Arivarasan A, Balaji VR, Raja JK, et al. Internet of Things based Smart Health Care System using LoRa. 2nd International Conference on Smart Electronics and Communication (ICOSEC); 2021:89–95. doi:10.1109/ICOSEC51865.2021.9591851
20. Lavric A, Petrariu AI, Mutescu P-M, Coca E, Popa V. Internet of things concept in the context of the COVID-19 pandemic: a multi-sensor application design. *Sensors*. 2022;22(2):503. doi:10.3390/s22020503
21. Han J, Song W, Gozho A, et al. LoRa-based smart IoT application for Smart city: an example of human posture detection. *Wirel Commun Mob Comput*. 2020:1–15. doi:10.1155/2020/8822555
22. Wu F, Rüdiger C, Redouté JM, Yuce MR. WE-Safe: a wearable IoT sensor node for safety applications via LoRa. IEEE 4th World Forum on Internet of Things (WF-IoT); 2018:144–148. doi:10.1109/WF-IoT.2018.8355234
23. Chen M, Yang J, Zhou J, Hao Y, Zhang J, Youn CH. 5G-smart diabetes: toward personalized diabetes diagnosis with healthcare big data clouds. *IEEE Commun Mag*. 2018;56(4):16–23. doi:10.1109/MCOM.2018.1700788
24. Wijethilaka S, Porambage P, de Alwis C, Liyanage M. A Comprehensive Analysis on Network Slicing for Smart Hospital Applications. IEEE 19th Annual Consumer Communications and Networking Conference (CCNC); 2022:276–279. doi:10.1109/CCNC49033.2022.9700535.
25. Chen Z. Design and analysis of adolescent physical health monitoring system under the background of internet of things and 5G. *J Healthc Eng*. 2021. doi:10.1155/2021/5208976
26. Sigwele T, Hu YF, Ali M, Hou J, Susanto M, Fitriawan H. Intelligent and Energy Efficient Mobile Smartphone Gateway for Healthcare Smart Devices Based on 5G. IEEE Global Communications Conference (GLOBECOM) 2018:1–7. doi:10.1109/GLOCOM.2018.8648031
27. Fouad H, Kamel H. A Proposed end to end Telemedicine System based on embedded system and mobile application using CMOS wearable sensors. International Telecommunications Conference (ITC-Egypt) 2021:1–6. doi:10.1109/ITC-Egypt52936.2021.9513888
28. Adil M, Khan MK, Jadoon MM, Attique M, Song H, Farouk A. An AI-enabled hybrid lightweight authentication scheme for intelligent IoMT based cyber-physical systems. *IEEE Trans Netw Sci Eng*. 2022. doi:10.1109/TNSE.2022.3159526
29. Mia MMH, Mahfuz N, Habib MR, Hossain R. An Internet of Things Application on Continuous Remote Patient Monitoring and Diagnosis. 4th International Conference on Bio-Engineering for Smart Technologies (BioSMART); 2021:1–6. doi:10.1109/BioSMART54244.2021.9677715
30. Faro A, Giordano D, Venticinque M. Deploying Wifi, RF and BLE sensors for pervasive monitoring and control. IEEE International Workshop on Metrology for Industry 4.0 and IoT; 2020:605–610. doi:10.1109/MetroInd4.0IoT48571.2020.9138187
31. Rahimoon AA, Abdullah MN, Taib I. Design of a contactless body temperature measurement system using Arduino. *Indones J Electr Eng Comput Sci*. 2020;19(3):1251–1258. doi:10.11591/ijeecs.v19.i3.pp1251-1258
32. Kansara R, Bhojani P, Chauhan J. Designing Smart Wearable to measure Health Parameters. International Conference on Smart City and Emerging Technology (ICSCET); 2018:1–5. doi:10.1109/ICSCET.2018.8537314
33. Biswas M, Rahman A, Kaiser MS, et al. Indoor Navigation Support System for Patients with Neurodegenerative Diseases. Brain Informatics: 14th International Conference, BI; 2021:411–422.
34. Rana AK, Sharma S. Internet of things based stable increased-throughput multi-hop protocol for Link Efficiency (IoT-SIMPLE) for health monitoring in wireless body area networks. *Int J Sens Wirel Commun Control*. 2021;11(7):789–798. doi:10.2174/2210327911666210120125154
35. Choi A, Noh S, Shin H. Internet-based unobtrusive tele-monitoring system for sleep and respiration. *IEEE Access*. 2020;8:76700–76707. doi:10.1109/ACCESS.2020.2989336
36. Kulkarni AS, Suchetha M, Kumaravel N. IoT based low power wearable ECG monitoring system. *Curr Signal Transduct Ther*. 2019;14(1):68–74. doi:10.2174/1574362413666180622105447
37. Sood R, Kaur P, Sharma S, Mehmuda A, Kumar A. IoT Enabled Smart Wearable Device - Sukoon. Fourteenth International Conference on Information Processing (ICINPRO); 2018:1–4. doi:10.1109/ICINPRO43533.2018.9096820
38. Yang Y, Wang Y, Lin Y, Jia L. IoT System for Collecting Vital Signs and Geographic Location Data of Mobile Users. International Conference on Communications, Information System and Computer Engineering (CISCE); 2020:163–168. doi:10.1109/CISCE50729.2020.00039
39. Liu C, Zhang X, Zhao L, et al. Signal quality assessment and lightweight QRS detection for wearable ECG SmartVest system. *IEEE Inter Things J*. 2018;6(2):1363–1374. doi:10.1109/JIOT.2018.2844090
40. Al-Khammasi S, Ali NS. Wearable Healthcare Indoor Monitoring System Based on Internet of Things. Palestinian International Conference on Information and Communication Technology (PICICT) 2021:65–70. doi:10.1109/PICICT53635.2021.00023
41. Li F, Valero M, Shahriar H, Khan RA, Ahamed SI. Wi-COVID: a COVID-19 symptom detection and patient monitoring framework using WiFi. *Smart Health*. 2021;19:100147. doi:10.1016/j.smhl.2020.100147