Chapter

Application of Internet of Things (IoT) in Biomedicine: Challenges and Future Directions

Robert Fuior, Alexandru Sălceanu, Cătălina Luca and Călin Corciovă

Abstract

The Internet of Things (IoT) is currently rapidly being incorporated into many fields, but there are still some fields, such as healthcare, where IoT adoption is much slower. Medical IoT refers to a range of medical devices and people that rely on wireless communication to enable healthcare data exchange, remote monitoring, and patient rehabilitation for a better quality of life for the patient. Medical IoT can provide better medical care and rehabilitation services under the careful supervision of the physician, resulting in more cost-effective systems for hospitals as well as for the patient. Due to the regulatory, ethical, and technological challenges of biomedical hardware, the growth of medical IoT is still inhibited. The chapter provides an overview of the various technologies and protocols used for the Internet of Medical Things (IoT), with an overview of the current technologies, applications, and challenges.

Keywords: wearable technology, medical devices, remote patient monitoring, healthcare, protocols

1. Introduction

The Internet of Things (IoT) is a network of individually identifiable connected things (sometimes referred to as devices, objects, and items) that offer services for intelligent computing [1]. IoT objects are also referred to as "smart things," which make it possible to carry out routine tasks in a logical manner. The Internet of Things also benefits human communication in good ways. The Internet of Things (IoT) includes a variety of technologies, such as pervasive computing, sensor technology, embedded systems, communication technologies, sensor networks, Internet protocols, etc., which ultimately support the economic development of contemporary civilizations [2]. IoT's basic tenet is the provision of seamless, all-pervasive connectivity between objects and people.

Given the commonalities between similar technologies and the confluence of three distinct ideas, it is difficult to establish a specific definition of IoT. In a nutshell, IoT is a system in which things are linked in such a way that they may intelligently interact with one another and with people. However, in order to better grasp the Internet of

Things, a number of standard organizations and development groups have established their own definitions [3].

1.1 Evolution of the IoT concept

The evolution of IoT with reference to technological progress in the conception of the Internet is presented in **Figure 1**. The concept of IoT, or the Internet of Things, refers to the interconnectivity of physical devices that are embedded with sensors, software, and network connectivity, allowing them to communicate with each other and with other systems over the Internet [4]. IoT has evolved over the years as a result of advancements in several areas of technology, including embedded systems, M2M communication, CPS, WSN, and the WoT.

These advancements have enabled the development of devices that can collect and transmit data, analyze and respond to that data in real time, and interact with other devices and systems. The development of the Internet itself has also played a critical role in the evolution of IoT. As the Internet has become faster, more reliable, and more widely available, it has made it possible to connect more devices and systems and to transmit larger amounts of data more quickly [5]. Overall, the evolution of IoT has been closely tied to technological progress in a range of areas, and it will likely continue to evolve as new technologies and capabilities become available.

These capabilities will be expanded through interactions with a wide range of electronic devices, according to the concept of the new IoT trend. In general, Internet-centric and Internet-centric items can be thought of as the IoT vision. The improvements of all technologies connected to the idea of "Smart Things" are included in the thing-centric vision. The Internet-centric vision, on the other hand, calls for the development of network technology to connect interactive smart objects with the storage, integration, and management of created data. These perspectives allow the IoT system to be understood as a dynamic dispersed network of intelligent objects that can generate, store, and consume the necessary information [6].

1.2 Application areas of the Internet of Things

Applications based on the Internet of Things (IoT) are expanding quickly, which is causing the world to change [7]. IoT's expansion has been a wonderful development in recent years. IoT is the interconnection of physical and digital items that have been fitted with sensors, software, and other technologies [8]. It entails using the Internet to communicate and exchange data with other systems and devices all around the world. IoT also resembles a group of network-capable gadgets that do not include desktop and laptop computers or servers. IoT has impacted a wide range of industries, starting with the healthcare industry. It is now implantable, wearable, and portable, creating a pervasive and interactive world [9]. It transforms the inanimate objects in

Figure 1.
Technological progression in IoT.

our immediate environment into intelligent objects, resulting in the creation of an information environment that raises the standard of living for people.

IoT devices, for instance, monitor and gather vital measurements (such as blood pressure, blood sugar level, pulse, etc.) in real time, enabling emergency alerts to raise the patient's likelihood of survival [10]. Furthermore, autonomous and self-driving cars assist drivers in getting where they are going by preventing them from going off the road or getting into accidents. Additionally, these definitions are expanded to include automatic emergency alerts for the closest roads as well as medical aid in the event of an accident. The Internet of Things also includes a wide range of contemporary industries, including the manufacturing, assembly, packaging, logistics, smart city, and aviation sectors [11]. **Figure 2** depicts a few of the most important IoT-based application sectors in the fields of health, business, communication, and entertainment.

Internet of Things (IoT) has numerous applications in the medical field, ranging from patient monitoring and diagnosis to drug development and supply chain management. Some of the medical application areas of IoT are:

- Remote patient monitoring: IoT can be used to remotely monitor patients' health conditions, vital signs, and medication adherence, allowing healthcare providers to deliver personalized care and intervene quickly if necessary. This can be

Figure 2.
Important application areas of the Internet of Things.

especially useful for patients with chronic conditions or those who live in remote areas.

- Wearable medical devices: IoT-enabled wearable devices, such as smartwatches, fitness trackers, and health monitors, can track patients' activity levels, sleep patterns, and other health metrics. This information can be used to provide personalized health recommendations and alerts and to help patients manage chronic conditions.

- Connected medical devices: IoT can connect medical devices such as blood glucose meters, blood pressure monitors, and ECG machines, allowing healthcare providers to remotely monitor patient data and provide real-time interventions when necessary.

- Telemedicine: IoT can be used to enable remote consultations between patients and healthcare providers, allowing patients to receive care from anywhere with an Internet connection. This can improve access to care and reduce healthcare costs.

- Drug development: IoT can be used to track drug efficacy and patient outcomes in clinical trials, allowing researchers to optimize drug development and accelerate the drug approval process.

- Supply chain management: IoT can be used to track the temperature, humidity, and other environmental factors that affect the quality and safety of pharmaceuticals and medical supplies during transportation and storage.

Overall, the medical application areas of IoT have the potential to improve patient outcomes, increase efficiency, and reduce costs in the healthcare industry [12–14].

2. IoT in biomedicine: Medical IoT

In the medical field, IoT can be useful in remote patient monitoring (monitoring blood pressure, checking heart rate, checking biometric parameters, or even checking hearing aids), it can be used in the management of diseases in chronic patients or in case of medical emergencies. The advantages of IoT systems used in medicine are that they can continuously and reliably monitor patients and facilitate the digital storage of patients' personal health information. This type of technology helps in the formation of medical databases and their interconnection for a much better management of patient care. Studies show that at this moment, IoT technology will lead to the greatest advances in medicine and will generate revolutionary treatments for patients [15].

IoMT or the Internet of Medical Objects represents the Internet of Things used in healthcare applications. This relatively new market is in continuous growth worldwide with a valuation of over 150 billion dollars in the year 2022 and an increase of $357.45 billion from 2022 to 2028. There are several IoMT solutions on the market but also at the study level that include sensors, wearable systems, including remote access to medical services and monitoring systems of daily activities or hospital systems that increase the quality of patient care, thus fully covering the need for patient care [16].

2.1 Technologies

At this moment in the market, when it comes to healthcare Internet of Things technology, there are several companies that are changing the way IoT is used in medicine. IoMT includes medical devices but with assault and monitoring of public health services, chronic patient care, and distance [17].

In the following lines, we will describe the main IoMT technologies and their principles.

2.1.1 Integrated platforms

Software and hardware integrations for multiple data extractions between medical devices are a real necessity at this point. In this direction, those at Elemental Machines have developed LabOps, a hardware and cloud-based software platform that helps laboratory operations for research and development, clinical laboratories, quality control, and diagnostics of the type [18].

Those from Philips have developed the Phillips Capsule Platform that allows the easy integration of devices used in patient monitoring, thus allowing much easier access to medical data [19].

Also, data about the environment in which we live can help medicine to detect and prevent diseases. Aclima is a platform created in partnership with Google, the Environmental Defense Fund, and researchers from the University of Texas at Austin, to measure air quality in big cities. A series of factors such as transport, energy consumption, and weather are taken into account. The collected data can thus be used in the prevention and management of cardiovascular and respiratory diseases [20].

2.1.2 Remote temperature store monitoring for vaccines

In less developed countries, IoMT tries to solve some apparently trivial problems, such as improving health conditions by creating conditions for storing and administering vaccines. This is how the ColdTrace System was developed, which provides remote temperature monitoring for refrigerators where vaccines are stored in rural clinics and health facilities. This way healthcare workers can safely administer life-saving vaccines [21].

Not only in less developed countries did this need to use IoT for monitoring the temperature in storage refrigerators appear. Even large pharmaceutical companies like Pfizer have adopted IoT in many ways. It has partnered with IBM and implemented IoT to help produce and distribute COVID-19 vaccines. Thus, Pfizer used IoT sensors to track and monitor shipments of COVID-19 vaccines and ensure safe temperatures over long distances [22].

2.1.3 Remote patient monitoring

The most common application of IoT devices for healthcare is remote patient monitoring security using sensors that can automatically collect biometric status values. Thus, the need for patients to travel to health centers or to collect the necessary parameters for correct monitoring was eliminated [23].

Remote patient monitoring using AI takes various forms; starting from simple systems that follow the sleep and breathing patterns of a baby (https://systemone.id)

and reaching systems that are capable of providing over 10 million diagnostic results for tuberculosis, Ebola, HIV by transmitting medical diagnostic data in real time [24].

Biometric data such as oximetry or blood pressure values obtained from patients can be uploaded to platforms such as Honeywell's Genesis Touch, which aims to keep patients connected with care providers through remote locations [25].

The IoT application in monitoring vital parameters is useful in collecting data about patients and assisting them in case of accidents. The software applications used are based on algorithms that can be used to analyze the data so that a treatment can be recommended or to generate alerts. The same principle is applied in their case of continuous and automatic monitoring of glucose levels in patients. They automatically record glucose values and can alert patients when glucose levels are problematic [26].

2.1.4 Depression and mood monitoring

There are numerous challenges related to monitoring a patient with depression or a bad emotional state because they are not always aware of the state they are in. In these situations, IoT devices can gather information about patients' depression symptoms and general mood by collecting and analyzing data such as heart rate, blood pressure, or eyeball movement [26].

A new method of monitoring these states was launched by the Abilify MyCite from Otsuka. They made an aripiprazole tablet (an antipsychotic drug used to treat various mental and mood disorders) embedded with an ingestible event marker (IEM) sensor. So the sensor sends data to a mobile app that allows users to then review "data on medication intake and activity level, as well as self-reported mood and rest quality." These data can be accessed through a secure web portal, by the attending physician, or by family members and friends [27].

2.1.5 Other examples of IoT/IoMT

IoT sensors manage to achieve continuous monitoring of Parkinson's patients' symptoms, giving patients the freedom to lead their lives in their own homes.

Apart from the portable devices presented, there are also devices in the IOMT that actually provide the patient's treatment. Some examples include devices for Hand hygiene monitoring, connected inhalers that can alert patients when they leave inhalers at home, ingestible sensors that collect information from digestive and other systems in a much less invasive way, or smart contact lenses [28].

Robots used in surgery represent an important branch of IOMT because with their help surgeons can perform complex procedures, thus reducing the size of incisions and faster healing for patients [29].

As a summary of what was previously presented, at this moment, according to the specialized literature, we can classify IoT in Biomedicine Technologies as follows:

- IoT-enabled biosensors
- Wound healing monitoring systems
- IoT-based disease monitoring systems
- Internet of nano-things healthcare applications

- Wearable IoT sensors for healthcare applications
- Degradable IoT sensors for healthcare applications
- IoT in medical implant manufacturing
- IoT in rehabilitation devices
- IoT-enabled medical robotics
- IoT in genomics
- IoT devices in pharmaceutical industries

2.2 Applications

The Internet of Things (IoT) has revolutionized the way we live our lives, yet studies show medical IoT modules are still not being used to their full potential. What is known for sure at this moment is that the Internet of Things can help transform the way health systems work and the way they provide patient care [29].

IoT in medicine is in a continuous development process and today manages to solve many medical care problems involving several levels.

Facilitating hospital management is made by room control systems, equipment monitoring and fault warning, management of equipment, medicines, and consumables, personnel performance analysis, and regulation of the flow of patients.

Improving the quality of medical services by using IoT in monitoring the vital signs of patients' health in operating and postoperative wards or online diagnostics through telemedicine solutions.

Improving the quality of the doctor-patient relationship by checking health indicators during the day with fitness bracelets, glucometers, and cuffs for measuring pulse, sending automatic reminders for activities, medications, or doctor visits, and notification of changes in vital signs with data [30] (**Table 1**).

Therefore, IoMT is a valuable technology for all players active in the health field, including public hospitals, private clinics, medical professionals of various profiles, insurance companies, and, of course, patients.

2.3 Challenges

Because we are talking about a new technology, it also faces many challenges in its application in the medical field. The main challenge is data security.

Remote patient monitoring devices cannot currently secure the collection of personal medical data. Data collected by medical devices qualifies as protected health information under HIPAA and similar regulations. As a result, IoT devices could be used as gateways for data theft if they are not secured. According to the latest studies, approximately 82% of healthcare providers report that they have experienced attacks against IoT devices.

Solutions would be the development of secure IoT hardware and software systems. Another challenge given the fact that no one at the moment can ensure that IoT devices in the health field are well managed, there is no protection system in place so that these devices are not used for other purposes than those that were created.

No	Application	Description	Problem-solving
1.	Patient care	IoT manages to ease the workflow for patient care with the help of innovative technologies that enable connectivity between medical devices saving money and time by reducing unnecessary travel of medical personnel [31, 32].	Improving the quality of medical services
2.	Patient record	The medical history part is time-consuming for the doctor, so IoT can transmit critical health data through sensors so that doctors can detect vital signs of deadly diseases in real time [33].	Improving the quality of medical services
3.	Medical assistance in medication administration	IoT helps the patient follow the medication plan correctly by issuing alarms when it is time to take their medication [34].	Improving the quality of the doctor-patient relationship
4.	Real-time patient monitoring	The use of sensors and the creation of intelligent medical systems that can be connected to a smartphone application is possible thanks to IoT technology. Thus, the data are easily collected and stored in the cloud in order to be able to monitor the patient's condition in real time [32].	Improving the quality of medical services
5.	Health Data Transmission	Medical data circulates and can be easily accessed using IoT devices. Thus, there are interconnected medical devices capable of transmitting a large amount of data in real-time applications, with IoT being responsible for constant data connectivity [35, 36].	Improving the quality of medical services
6.	Preventing and reducing the rate of intra-hospital infection	Environmental monitoring systems, hygiene control as well as pharmacy inventory tracking with the help of IoT can significantly reduce the distribution of infection among patients as well as in the hospital environment [37].	Improving the quality of medical services
7.	Making the work of doctors more efficient	IoT systems help the doctor in the relationship with the patient, relieving him of repetitive work and leaving him more time for the patient. Thus there are systems that record information about the patient with the help of voice commands and ease the doctor's work [38].	Improving the quality of medical services
8.	Telemedicine	Remote care and real-time monitoring are possible today due to the integration of IoT in medicine and the creation of a new field—telemedicine. Thus, doctors and nurses in hospitals are relieved of a large number of patients who can be monitored and cared for at home [39].	Improving the quality of medical services Improving the quality of the doctor-patient relationship
9.	IoT Hospital Management Systems	IoT-based hospital information and management systems are designed to remotely manage medical staff, medical supplies, and patient activities in the hospital. Medical staff analyze the data, which is then interpreted by hospital information and management systems. These systems are centered on the patient to increase the quality of the medical act [40].	Facilitating hospital management
10.	Rapid diagnosis	IoT systems used in monitoring can issue alerts when significant changes occur in patients' vital parameters. In this way, patients in real need of assistance can be easily identified and care teams can be directed. Thus, there is a simplification of medical procedures useful for the patient, doctors, and medical care staff [41].	Improving the quality of medical services Improving the quality of the doctor-patient relationship

No	Application	Description	Problem-solving
11.	AI and Deep Learning	Deep Learning is an AI technique used in the medical field to analyze collected data and facilitate diagnosis. The use of deep learning techniques and the mining of personal medical data collected by remote healthcare devices and sensors has revolutionized medical treatment and disease prevention [42].	Improving the quality of medical services

Table 1.
Different monitoring applications with the help of IoT.

It is also not legal to decommission patient monitoring devices that have an older version of software or firmware that makes data theft possible.

The solution to these challenges would be to correctly discover and classify all IoT devices in a healthcare provider's network. Thus, once networks of IoT devices are identified, classified, regulated, and secured in an established manner, managers can track device behavior to identify anomalies, perform risk assessments, and segment vulnerability against mission-critical devices [43, 44].

At this moment, an important challenge is represented by the final cost of medical devices. That is why studies are directed toward the design of IoT devices with sensors at affordable prices, easy to install, and maintain [45].

The general conclusions regarding the implementation of IoT in healthcare will be based on the existence of a clear and robust code of practice for data management, privacy, and cyber security. At this moment, IoT in medicine is limited to applications in the form of research projects in the field of health. The results of the current studies provide an excellent opportunity for healthcare systems to proactively predict health problems and diagnose, treat, and monitor patients both in and out of the hospital.

It is predicted that in the future, more traditional healthcare delivery practices will be supplemented or replaced by the IoT, as the adoption of technology-enabled healthcare services increases and enables healthcare systems to offer flexible models of care. In the context of IoT-enabled medical service delivery, more research is needed on the efficiency of blockchain storage compared to centralized cloud-based storage solutions (**Figure 3**).

Clinical guidelines on digital health prescriptions and the adoption of sound policies on the remuneration of primary and secondary care services delivered through IoT also need to be legislated.

All these aspects must be supported through research, in order to finally obtain a rate of acceptability and increased digital literacy of consumers and clinicians in the context of IoT use [46].

Another important aspect is that the technical preparation necessary for the implementation of IoT by those who offer medical services was not taken into account, even though the complete digitization of the medical sector is being attempted. Also, medical clinics must solve the cyber security problem and cover the lack of an adequate infrastructure for the implementation of IoT in health systems [32].

2.4 Future directions

The Internet of Things (IoT) is a fascinating technology and the possibilities of application in the medical field are limitless.

Figure 3.
Introducing medical IoT challenges.

At this moment, future research directions focus on the development of ingestible sensors and nanotechnologies that can help collect medical data in real time.

Robotic surgery has already been used in specific healthcare applications that require stable and long operational procedures.

Another field in which IoT will find applicability is the field of health insurers who will use IoT devices to calculate risk premiums with a long-term effect on patients with chronic diseases.

Companies like Google have already filed patents for contact lenses and other healthcare IoT technologies.

Health systems can be improved with the help of IoT, which can bring many benefits: simplifying decisions, reducing costs, creating better and personalized treatment plans, more efficient results, and, finally, a healthier life.

These benefits will also come with challenges such as building secure and easy-to-use IoT devices with the right software and a secure system in terms of data security [32].

3. IoT in biomedicine: Rehabilitation IoT

Health sciences are fields of study related to life and include several branches such as medicine, biomedicine, nursing, speech therapy, clinical criticism, pharmacy, physical health, dentistry, psychology, occupational therapy, nutrition, and physical therapy. All these fields consider the use of science, technology, engineering, or mathematics to provide medical care to human beings. Many people experience physical and/or motor limitations associated with a variety of reasons, whether due to problems at birth, work-related accidents, or restrictions caused by aging. Older people are more affected by motor impairments that make even simple daily tasks difficult, such as lifting an object without difficulty, eating alone, or even dressing. Such consequences can restrict personal activities and avoid the full participation of the elderly in the community, which has a negative effect on their daily work and life in general [47].

Currently, the Internet of Things (IoT) has a significant impact in the field of medical rehabilitation as well. By connecting devices and sensors to the Internet, IoT facilitates the collection and analysis of real-time data, thereby enabling medical staff to monitor patients more effectively and provide personalized treatments. Some examples of the importance of IoT in medical rehabilitation are:

1. *Patient monitoring:* IoT devices can be used to constantly monitor patients' vital parameters such as blood pressure, heart rate, and blood oxygen level. This data can be transmitted in real time to doctors and nurses, allowing them to track the patient's progress and intervene if changes or problems arise [48].

2. *Remote therapy:* IoT technologies can enable the delivery of remote therapy through Internet-connected devices. For example, patients can use wearables or mobile apps to guide them through rehabilitation exercises and collect data on their performance. Therapists can access this data and provide real-time feedback to adjust treatment and monitor patient progress.

3. *Assistive and assistive devices:* IoT can facilitate the use of assistive and assistive devices, such as smart prosthetics or robotic rehabilitation devices. These devices are equipped with sensors and can be connected to the Internet to enable data collection and real-time adjustment of operating parameters. Thus, patients can benefit from more effective and personalized rehabilitation.

4. *Inventory and equipment management systems:* In a medical environment, IoT can be used to monitor equipment and drug stocks and automatically send alerts when restocking is required. This can help to streamline processes and ensure uninterrupted operation of medical services.

5. *Data analysis and research*: By collecting and analyzing data from IoT devices, researchers and doctors can gain valuable information about the evolution of patients over time, the effectiveness of different treatments, and the factors that influence the rehabilitation process. This information can contribute to the improvement of medical practices and the development of new technologies and approaches in the field of medical rehabilitation [49].

3.1 Technologies

The architecture of an IoT (Internet of Things) system for medical rehabilitation usually involves the integration of different components and technologies to monitor, collect, and analyze data related to the rehabilitation process. A high-level architecture overview is described below:

3.1.1 Sensors and wearables

These are the physical devices that capture data about the patient's movements, vital signs, and other relevant information. Examples include motion sensors, accelerometers, heart rate monitors, electromyography (EMG) sensors, and wearable devices such as smartwatches or fitness trackers. These sensors and devices are worn by the patient and communicate wirelessly with the IoT system [50, 51].

3.1.2 Data acquisition and communication

Data collected by sensors and wearable devices is transmitted to a gateway device or directly to the cloud for processing and analysis. This communication can be done using different wireless protocols such as Wi-Fi, Bluetooth, or Zigbee. The gateway device acts as a bridge between the sensors and the cloud, relaying the data securely.

3.1.3 Cloud platform

The cloud platform serves as a central hub for data storage, processing, and analysis. It receives data from sensors and wearable devices and stores it in a secure and scalable way. The cloud platform also provides the computing resources required for real time or batch processing of the data, depending on the requirements. Popular cloud platforms such as Amazon Web Services (AWS) or Microsoft Azure are often used to host IoT infrastructure.

3.1.4 Data processing and analysis

Collected data is processed and analyzed to obtain meaningful information about the patient's rehabilitation progress. This can involve various techniques, such as signal processing, machine learning, or statistical analysis. The data processed may include metrics such as range of motion, muscle activity, exercise adherence, or performance indicators. This information can be used to tailor rehabilitation programs, track progress, and provide feedback to the patient and healthcare professionals.

3.1.5 Application and user interface

Processed data are made available to various stakeholders, including patients, caregivers, and health professionals, through user-friendly applications and interfaces. These interfaces can be web portals, mobile apps, or specialized software used in rehabilitation clinics. They provide real-time feedback, visualizations, and progress reports to help monitor and manage your rehabilitation process.

3.1.6 Security and privacy

Given the sensitive nature of medical data, security and privacy measures are crucial in a medical rehabilitation IoT system. This includes encryption of data during transmission and storage, access control mechanisms, user authentication, and compliance with relevant data protection regulations such as the United States' Health Insurance Portability and Accountability Act (HIPAA). IoT architecture should ensure that patient data is handled securely and that the system is resilient to potential cyber security threats (**Figure 4**) [52].

It is important to note that the specific architecture may vary depending on the requirements of the rehabilitation program, the type of medical condition being treated, and the available technologies. The architecture presented above provides a general framework for understanding the key components involved in an IoT system for medical rehabilitation.

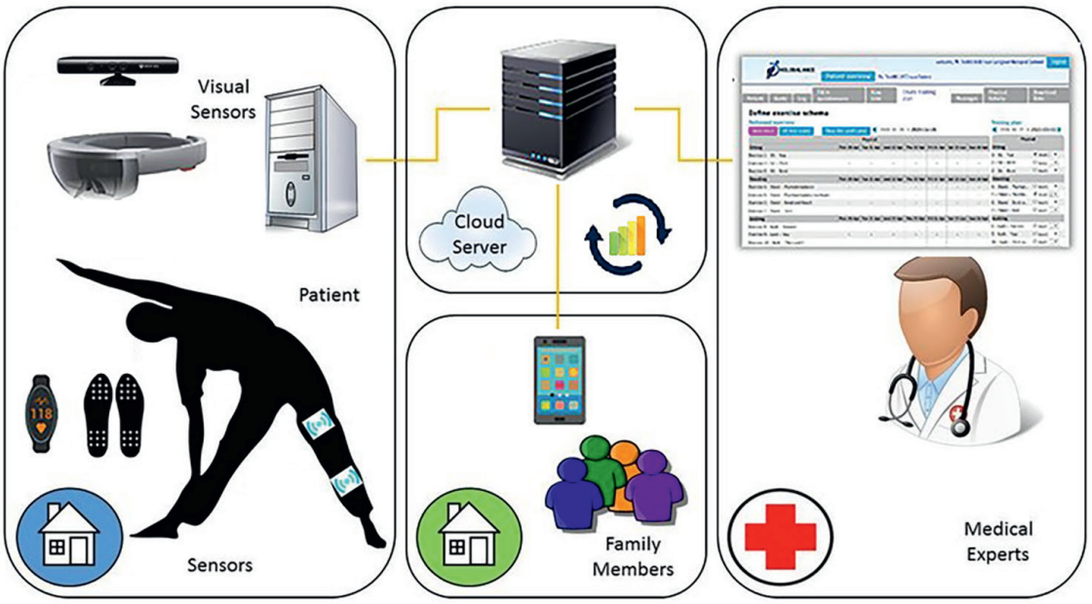

Figure 4.
System overview of the home-based rehabilitation system.

3.2 Applications

The use of IoT (Internet of Things) in medical rehabilitation can improve the effectiveness, efficiency, and convenience of rehabilitation programs. IoT data can be used to tailor rehab programs to the specific needs of individual patients. Data collected from wearables and sensors can be used to identify areas of strength and weakness, and rehabilitation programs can be designed to target these areas. Personalized approach can help patients achieve better results and reduce the risk of injury.

An example of a BSNCare+ system is where IoT-based rehabilitation equipment is embedded for both the patient and the involved environment as an end-to-end device. The nurse can use the mobile gateway to collect data in real time and offer better-quality medical services to the patient. All detection data will be transmitted to the BSN-Care server and maintained for the purpose of further data analysis and analysis of patient needs [53] (**Figure 5**).

Body Sensor Networks (BSN) take the concept of wearables to the next level. BSNs consist of a network of wearable sensors that can communicate with each other and

Figure 5.
Proposed IoT-based communication architecture for BSNCare+.

Figure 6.
Portable medical and healthcare devices worn on body parts used in medical rehabilitation IoT systems.

with other devices. BSNs can provide real-time monitoring of multiple physiological parameters, making them useful for a wide range of applications, including medical rehabilitation [54] (**Figure 6**).

IoT devices can be used to create virtual rehabilitation environments simulating real-world activities. Virtual reality headsets, for example, can be used to create immersive experiences that can help with the rehabilitation process. Virtual rehab can also allow patients to practice their rehab exercises in a safe and controlled environment.

Gamification is using game design principles to motivate and engage patients in their rehabilitation program. IoT devices can be used to create gamified experiences that make rehab more fun and engaging. For example, sensors can be used to track a patient's movements during an exercise, and the data can be used to control a video game. This can make rehabilitation more enjoyable and increase patient adherence (**Figure 7**).

IoT devices can be used to provide remote guidance and support to patients during their rehab program. Video conferencing tools, for example, can be used to connect patients with rehabilitation professionals who can provide guidance and feedback on their exercise. This can be particularly useful for patients who live in remote areas or have limited access to health professionals [55].

Overall, the application of IoT in medical rehabilitation has the potential to transform the way patients receive rehabilitation services. By providing real-time data, personalized programs, and remote coaching, IoT can improve patient outcomes, reduce costs, and increase patient satisfaction.

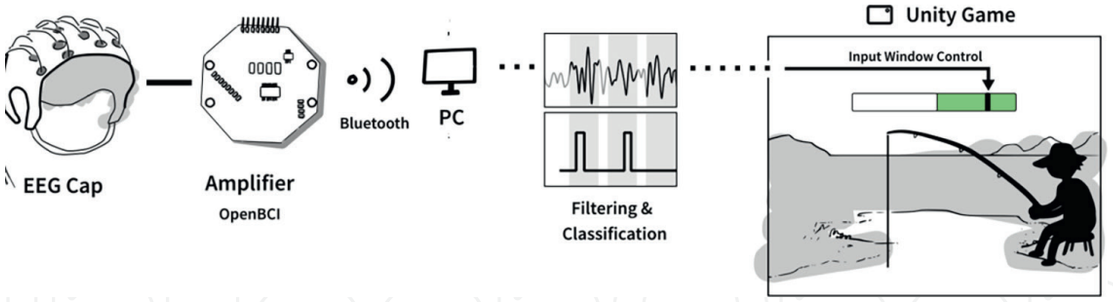

Figure 7.
Brain-computer interfaces (BCIs) and IoT for stroke rehabilitation using gamification.

3.3 Challenges

While the use of IoT (Internet of Things) in medical rehabilitation brings many benefits, there are also some challenges that need to be addressed. The accuracy and reliability of data collected by IoT devices are crucial for effective decision-making in rehabilitation. However, there may be situations where IoT devices produce inaccurate or inconsistent data due to device limitations, calibration issues, or user error. Adequate calibration, regular maintenance, and validation processes should be implemented to ensure the accuracy and reliability of IoT-generated data.

Privacy is provided by standardized data security protocols (such as encryption, authentication, and key distribution) during the data collection phase. In cases where security protocols are not suitable for IoT devices or cannot meet the application requirements, specific encryption, authentication, or key distribution algorithms are proposed. In these situations, there may also be issues related to indirect privacy leaks, such as finding user behavior patterns and protecting user anonymity. In the data transmission and storage/sharing phases, the individual system design must be made according to specific policies or rules that provide privacy to system users [56].

IoT devices and associated applications should be user-friendly and intuitive to ensure compliance and patient engagement. Complex user interfaces or difficult-to-use devices may deter patients from actively participating in their rehabilitation programs. Designing devices and interfaces with the end user in mind, conducting usability tests, and collecting user feedback can help improve the overall user experience.

IoT devices collect and transmit sensitive patient data, including personal health information. Ensuring the security and confidentiality of this data is crucial to protecting patient privacy. Healthcare providers must implement robust security measures such as encryption, secure data storage, access control, and regular system updates to protect patient data from unauthorized access or cyber threats [57]. The solution is to develop uniform data quality standards. In this way, it can be managed more efficiently across countries, organizations, and departments, thereby facilitating the storage, delivery, and sharing of data and reducing errors in judgment and decision-making due to data incompatibility, data redundancy, and data deficiencies. Since IoT systems are distributed in nature, the use of international standards can have a positive effect on improving the performance of business processes by aligning different organizations with the same foundation, addressing interoperability issues, and ultimately working in a seamless manner [58].

IoT devices in medical rehabilitation collect extensive data about patients' movements, health conditions, and activities. Healthcare providers must address ethical concerns about data ownership, consent, and use. Patients must be informed about the data collected, how it will be used, and have control over their data. Implementing clear data governance policies and complying with relevant privacy regulations are essential. Implementing IoT in medical rehabilitation may require significant investments in hardware, software, infrastructure, and ongoing maintenance. Healthcare providers need to assess the cost implications and ensure the availability of necessary infrastructure and resources to support IoT implementation effectively [59].

Addressing these challenges requires collaboration among healthcare providers, technology developers, regulatory bodies, and other stakeholders. By addressing security concerns, promoting interoperability, ensuring data accuracy, and prioritizing user experience, IoT can realize its potential to transform medical rehabilitation while providing safe and effective patient care.

3.4 Future directions

The future direction of IoT (Internet of Things) in rehabilitation is poised to bring significant advances and benefits to the field.

Here are some possible evolutions and trends:

Smart devices and sensor technology: IoT-enabled smart devices and sensor devices will continue to play a crucial role in rehabilitation. These devices can monitor and collect real-time data about patients' movements, muscle activity, heart rate, and other vital signs. This data can be analyzed to provide customized feedback, track progress, and optimize rehabilitation programs.

Adaptive and personalized rehabilitation: The IoT can contribute to adaptive and personalized rehabilitation programs. By integrating sensors into rehabilitation equipment, IoT systems can automatically adjust resistance, range of motion, or intensity based on the patient's capabilities and progress. This personalized approach can optimize the efficacy of therapy and improve patient outcomes.

Data analytics and machine learning: The large amount of data generated by IoT devices in rehabilitation presents opportunities for data analytics and machine learning. By analyzing large datasets, patterns and insights can be identified to improve rehabilitation protocols, predict patient outcomes, and optimize treatment plans. Machine learning algorithms can also help automate rehabilitation progress assessment and provide personalized recommendations.

Gamification and virtual reality: IoT can use gamification and virtual reality (VR) technologies to make rehabilitation engaging and motivating. IoT-enabled devices can connect to VR platforms, allowing patients to interact with immersive environments that simulate real-life scenarios. Gamified experiences can increase patient participation, therapy adherence, and overall motivation, leading to improved rehabilitation outcomes.

Collaborative ecosystems: The future of IoT in rehabilitation will involve developing collaborative ecosystems. Different stakeholders, including healthcare providers, device manufacturers, software developers, and researchers, will work together to create integrated solutions. These ecosystems will promote interoperability between devices, secure data sharing, and standardized protocols, encouraging innovation and progress in rehabilitation practices.

Ethical and security considerations: As IoT becomes more widespread in rehabilitation, it is critical to address ethical and security concerns. Patient confidentiality, data security, and informed consent must take precedence. Robust security measures, such as encryption and authentication protocols, should be implemented to protect sensitive patient information from unauthorized access [60, 61].

Overall, the future of IoT in rehabilitation has a great potential to transform the way rehabilitation is carried out. Using IoT technologies, healthcare professionals can provide more personalized, efficient, and accessible rehabilitation services to improve patient outcomes and quality of life.

4. Conclusions

In the medical field, IoT enables remote patient monitoring, which improves the ability to diagnose and treat various conditions. Wearable devices equipped with sensors can collect real-time data on vital signs, medication adherence, and physical activity, providing healthcare providers with valuable information about patient health. This data can be analyzed to detect early warning signs, prevent complications, and facilitate timely interventions. IoT also enables telemedicine and virtual consultations, allowing healthcare professionals to connect remotely with patients, provide guidance, and monitor their progress.

In addition, IoT plays a crucial role in rehabilitation. Connected devices can help physical therapy by tracking movements, providing feedback, and guiding patients through exercises. This real-time monitoring helps to ensure correct form and adherence to prescribed regimens. IoT-based rehabilitation tools also enable remote rehabilitation, allowing patients to receive therapy from the comfort of their homes, thus increasing accessibility and convenience. Not only does this save time and cost, it also promotes patient engagement and adherence to treatment plans.

Despite these challenges, integrating IoT into medicine and rehabilitation holds immense promise for transforming healthcare delivery. It improves patients, improves outcomes, and revolutionizes how healthcare is practiced. As technology continues to advance and healthcare systems embrace IoT solutions, we can expect to see new advancements and innovations in this area, ultimately leading to a more connected and patient-centric healthcare ecosystem.

Conflict of interest

The authors declare no conflict of interest.

Author details

Robert Fuior[1,2], Alexandru Sălceanu[1], Cătălina Luca[2] and Călin Corciovă[2*]

1 Faculty of Electrical, Energy and Applied Informatics Engineering, "Gheorghe Asachi" Technical University of Iasi, Romania

2 Faculty of Medical Bioengineering, "Grigore T. Popa" University of Medicine and Pharmacy of Iasi, Romania

*Address all correspondence to: calin.corciova@bioinginerie.ro

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