Impact of Internet of Things (IoT) on Healthcare in Transforming Patient Care and Overcoming Operational Challenges

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Abstract

Background: The Internet of Things (IoT) is revolutionizing healthcare by introducing intelligent systems that improve patient monitoring, diagnosis, and treatment while addressing challenges like inefficiencies, high costs, and limited access to quality care. By leveraging IoT-enabled devices, healthcare can enhance accessibility, efficiency, and outcomes, especially in chronic disease management, pediatric care, and surgical procedures. Methods: This study employs a comprehensive review methodology, synthesizing peer-reviewed articles, industry reports, and case studies to assess IoT's impact in healthcare. The focus areas include the role of wearable sensors, remote patient monitoring systems, and automated medical equipment. Key challenges, such as data security, privacy concerns, and interoperability, are analyzed alongside proposed solutions for seamless integration. Results: IoT applications in healthcare demonstrate transformative potential. Devices such as insulin pumps, pacemakers, and smart baby monitors provide real-time data to enhance medical decision-making and patient care. IoT technologies improve chronic disease management, enable precise surgical assistance, and enhance pediatric care. However, issues like data breaches and compatibility between devices remain critical hurdles. Conclusion: The integration of IoT in healthcare marks a paradigm shift toward patient-centered, efficient, and accessible services. Addressing challenges related to security, privacy, and system compatibility through collaborative efforts among policymakers, healthcare providers, and technology developers will be crucial. IoT stands as a cornerstone for future innovations in healthcare, promising improved health outcomes and operational efficiencies.

Keywords: Internet of Things (IoT), Healthcare innovation, Remote patient monitoring, Chronic disease management, IoT integration challenges

Significance | IoT revolutionizes healthcare by enhancing patient monitoring, treatment, and accessibility while addressing challenges in efficiency, cost, and security.

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1. Introduction

The Internet of Things (IoT) is transforming our lifestyles and professional environments, with particularly profound implications for healthcare. The Internet of Things (IoT) fundamentally links objects to gather and disseminate data, providing more intelligent, rapid, and efficient methods for

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managing intricate processes (Ifty et al., 2024). In healthcare, where efficiency, accessibility, and precision are paramount, the Internet of Things (IoT) presents a novel opportunity to address urgent issues such as escalating prices, restricted access to quality care, and inefficiencies inherent in conventional systems (Khanna & Misra, 2014). These concerns are especially pressing in the contemporary world, when the need for accessible and efficient healthcare is perpetually increasing (Weber, 2010; Greaves et al., 2018).

The Internet of Things has commenced its transformation of the healthcare sector. Wearable sensors, remote monitoring systems, and automated drug dispensers facilitate real-time patient monitoring, early issue diagnosis, and personalized treatment regimens for healthcare providers (Atzori et al., 2010). Wearable gadgets can continuously monitor vital signs, while remote monitoring enables physicians to observe patients without necessitating hospital visits (Ashakin et al., 2024). These technologies conserve time and resources, enhance patient outcomes, and increase healthcare accessibility, especially for individuals in remote or disadvantaged regions (Hakim & Hoque, 2023; Ifty et al., 2023a). The effect is particularly evident in the management of chronic diseases, when consistent monitoring and prompt interventions are essential (Li et al., 2018). The significance of IoT in healthcare is evident, although its execution presents obstacles. Safeguarding sensitive patient information from breaches, guaranteeing interoperability among devices, and addressing privacy concerns are critical considerations. IoT systems manage huge volumes of medical data, rendering security a paramount concern (Kodali et al., 2015; Ifty et al., 2023b). Furthermore, the absence of standardized communication protocols across devices can impede effective integration. Addressing these difficulties necessitates cooperation among politicians, healthcare practitioners, and technological innovators.

This study is to examine the impact of IoT on healthcare, emphasizing its practical applications, advantages, and the challenges that need to be overcome. It analyzes the function of IoT in domains such chronic disease management, pediatric care, and surgical aid, providing concrete instances of its disruptive capabilities. The study examines advancements and associated problems, emphasizing solutions for more effective integration of IoT in healthcare.

2. Methodology

This study utilizes a thorough review-based methodology to examine the role of the Internet of Things (IoT) in healthcare. It consolidates information from peer-reviewed papers, industry reports, and case studies to assess IoT applications, innovations, and obstacles in the healthcare sector. The study examines several IoT applications, such as wearable sensors, remote patient monitoring systems, and intelligent medical equipment, assessing their effects on patient outcomes, healthcare efficiency, and cost savings. The research methodically delineates critical domains of IoT use, including chronic disease management, pediatric healthcare, surgical accuracy, and emergency response systems. It also analyzes recorded challenges such as data security, privacy issues, and interoperability problems, providing insights into how to mitigate these obstacles. A case-based methodology emphasizes practical instances, such as the use of Remote Patient Monitoring (RPM) systems in the management of chronic conditions and enhancement of care accessibility. The study underscores the necessity of coordination among stakeholders, such as legislators, healthcare providers, and technology developers, to facilitate effective IoT integration. This methodology integrates theoretical analysis with actual case studies, presenting a balanced perspective on the transformation of healthcare by IoT and providing actionable insights for future research and implementation.

3. IoT Devices for Medical Use

Healthcare services could experience an enormous shift because of the Internet of Things. It is transforming the healthcare industry by prioritizing improved patient care, cost reduction, and increased efficiency (Salam et al., 2024). In this area, we will delineate some IoT-enabled devices that the healthcare business can employ. Remote monitoring will provide global access to high-quality healthcare. Sensors collect data which advanced algorithms then evaluate. Medical workers can remotely access this information to diagnose patients and administer therapies. Furthermore, medical workers can closely observe patients to detect subtle changes and prevent drug overdose. We classify these gadgets based on their intended usage (Ashakin et al., 2024).

3.1 IoT for Young Children

3.1.1 Multiple-Input Multiple-Output (MIMO)

The Mimo smart baby onesie, developed by Rest Devices in Boston, utilizes a built-in sensor in the shape of a turtle to monitor an infant's respiration, skin temperature, body position, level of physical activity, and sleep patterns. Mimo transfers information to the cloud, making it accessible on a personal computer or mobile device. This sort of technology can be highly advantageous for working parents (Azzawi et al., 2016).

3.1.2 Milk Nanny

Milk powder is used to produce milk specifically for young children. The world's inaugural fully automated intelligent formula machine effortlessly creates warm, freshly prepared infant milk within a matter of seconds, ensuring consistent and precise results with one simple click. It is critical to maintain a constant ratio of water and power to avoid any adverse effects on the infant's dilution system. You can control it directly from your phone, making it more convenient (Chianese, et al., 2019).

3.1.3 TempTraq

TempTraq is a unique thermometer that uses Bluetooth technology to measure and monitor a child's temperature for 24 hours. It achieves this by using a soft patch. The wearable device transmits real-time data to a caretaker's mobile device (Chu et al., 2018).

3.1.4 Smart Nappies

Researchers at the University of Tokyo have designed a super-thin sensor that can go inside nappies to inform caretakers when it's time for a change. Furthermore, these Smart Nappies enable parents to conveniently and discreetly detect urinary tract infections, dehydration, or emerging kidney issues (Dadkhah et al., 2021).

3.2 IoT for Chronic Care

The widespread adoption of wearable technology, including by individuals with chronic conditions, has attracted much attention due to its proven benefits. The push buttons on the gadgets possess the capability to promptly transmit signals for urgent medical attention (Gupta et al., 2017)

3.2.1. Insulin Pump

Insulin pumps are tiny devices, similar in size to mobile phones that are utilized for the purpose of dispensing insulin in doses that can be changed by the user and have been preprogrammed. The insulin pump effectively regulates blood glucose levels by helping to correct both high and low blood glucose levels (Kuddus et al., 2022). Individuals use insulin pumps to reach their target A1C level. According to the United Kingdom Prospective Diabetes Study (UKPDS), maintaining strict control over blood glucose levels can delay or prevent the onset of microvascular complications, such as retinopathy (eye disease), nephropathy (kidney disease), and neuropathy (nerve damage), in individuals with Type 2 diabetes (Hayes et al., 2023). Using an insulin pump alone does not guarantee precise control of blood glucose levels. However, research has shown that pumps can help users achieve control that is equal to or even superior to that of individuals using insulin injections (General Electric Measurement & Control Solutions).

3.2.2 Pacemaker

A pacemaker is an implantable medical device that is positioned beneath the skin and connected to the heart via wiring to regulate abnormal heart rhythms. There is a rapid increase in the installation of pacemakers and implanted cardioverter defibrillators (ICDs) in modern Western countries. These devices control the heart's rhythm and, if needed, stimulate the appropriate reaction to ensure that the heart beats at the correct rhythm. They also record the heart's activity patterns when they detect an arrhythmia (Khatun et al., 2024). A medical practitioner regularly examines and monitors this data to strategies future treatment plans. To accomplish this, they wirelessly transmit the data to an external device. Presently, hospitals serve as the setting for this communication (Moushumi et al., 2024).

3.2.3 Measurement of Temperature

When a thermometer contacts the surface, it will precisely measure the temperature of that surface. If the surface is the skin of a human body, it will accurately measure the surface temperature. Medical equipment commonly uses NTC thermistors. They can withstand temperatures ranging from -196°C to 1000°C thanks to the use of transition metal oxides (Rana et al., 2023).

3.2.4 Inhaling CO

It is crucial for understanding the potential dangers and identifying any nearby devices that may be emitting carbon monoxide (CO). You can detect any leaks of this toxic gas in your residence by installing a carbon monoxide alarm, which emits a high-frequency sound to promptly notify you of elevated gas concentrations. These items are available for purchase at hardware stores. Although alarms are useful, they cannot substitute for regular maintenance and repair of household equipment. Poorly maintained, incorrectly placed, and inadequately vented household appliances, such as heaters, ovens, and central heating boilers, are the main sources of carbon monoxide. Blocked chimneys and flues can cause the accumulation of harmful levels of carbon monoxide (Ashakin et al., 2024).

3.3 IoT for Children

3.1 Swim band

The Swim Band is a compact and effective anti-drowning device specifically created to ensure personal safety in water. It can be used in bodies of water such as lakes, rivers, and pools to ensure the safety of children in the water. The wearable device can be worn either as a band or a headband, and it includes a built-in sensor that detects if it has been submerged for a duration specified by the user. Once the barrier is breached, it employs Bluetooth technology to send an alert to a companion iOS application located within a range of up to 100 feet (Ifty et al., 2024).

3.3.2 Monitoring of Sleep

A restful and refreshing night's sleep indicates optimal health. Sleep monitoring devices offer optimal sleeping settings that are both natural and comfortable. The device measures a range of parameters, such as blood pressure, body temperature, and joint and body movement (Li et al., 2018).

3.4 IoT for Body Motion Reconstruction and Motion Detection

A wearable motion-tracking device monitors the motions of a patient's body segments. A reconstructed human model can then display these movements. We use the human model to assess the rotational angles of the afflicted joints in both lower extremities (hip and knee) and upper extremities (elbow and wrist). We then correlate these measurements with two symptoms, namely resting tremors and bradykinesia. The technology is quite beneficial for monitoring a patient's activity in the intensive care unit (Li et al., 2018)).

3.5 IoT for Personal Emergency Response Systems (PERS) and Man-down

3.5.1 Measuring Blood Pressure

The tonometer is an essential medical device that is vital in both home and hospital settings. However, the current tonometer presents a drawback as it necessitates the application of significant pressure to the artery and can only record blood pressure readings over five consecutive checks. Consequently, individuals with hypertension are unable to utilize the existing tonometer to continually monitor their blood pressure for a whole 24-hour duration. The standard Korotkoff method, as employed by the National Health Service (NHS), utilizes air pressure cuffs and stethoscope to evaluate a patient's blood pressure. Doctors continue to employ this method to assess patients' blood pressure in the present day (Bari et al., 2023). With the advancement of information technology, the prevalence of automatic electronic tonometer has increased in both households and hospitals due to their portability and significant utility. Because it uses the Oscillo metric approach, which is essentially an improved version of the Korotkoff method, this device shares the same drawback as a standard tonometer: it temporarily halts the flow of blood in the artery, a potentially fatal condition (Ifty et al., 2024).

3.6 IoT for Surgical Guidance

Surgeons in operating theatres must authenticate multiple reports or x-rays. A higher proportion of surgical procedures achieve success due to the utilization of Google Glass, which provides surgeons with rapid and convenient access to data, hence enhancing their confidence in decision-making (Li et al., 2018).

3.7 Medicine Dispenser

Research suggests that those who ignore their doctor's prescribed medication might face significant consequences, especially among senior patients. Researchers have developed an automated pill dispenser that leverages mobile phones, wireless M2M technology, and the Internet of Things. The gadget's magic lies in its powered pillbox, which contains a secure M2M Bluetooth module manufactured by Gemalto (the Interion PHS8 smart card). This module enables an automated wireless connection between the pillbox and the patient, physician, family member, and medical alert monitoring center, ensuring constant communication. The sensor-equipped dispenser monitors the quantity of medication used, regardless of whether the container is open or closed, and sends this information to a central server over a wireless network (STMicroelectronics, n.d.).

4. IoT in Healthcare

The health care sector is currently experiencing significant and fundamental change due to the influence of the Internet of Things (IoT) (Table 1). This technology is revolutionizing medical service delivery and management. A healthcare system is a complex network of institutions, services, and experts dedicated to providing medical care and enhancing general health, comprising hospitals, clinics, primary care physicians, specialists, and additional services(Wendt et al., 2009). These entities collaborate to effectively meet the healthcare requirements of both individuals and communities. Nevertheless, the healthcare system has substantial obstacles that can hinder its effectiveness and progress.

Data security and confidentiality are of utmost importance, especially as healthcare organizations increasingly depend on digital technologies for the storage and management of patient information. Their dependence on this makes them more vulnerable to data breaches and cyberattacks, necessitating strong safeguards to protect sensitive medical data. Moreover, the incorporation of various technologies in healthcare settings poses a significant obstacle. The diverse range of instruments and software systems utilized must operate harmoniously, but incompatibilities might result in data mistakes, delays in care, and heightened expenses(Poongodi et al., 2019). Furthermore, rising healthcare costs and scarcity of resources impose additional limitations on the availability of medical services, resulting in a decline in service quality. The incorporation of IoT technology in healthcare presents novel solutions to these obstacles by establishing a network of networked devices that gather, exchange, and analyze data to improve healthcare provision (Chianese et al., 2019).

The IoT's vision focusses on using intelligent devices to monitor health data in real-time. It also emphasizes the use of standardized communication protocols for seamless data transfer over the internet. Additionally, the IoT utilizes advanced analytics to support healthcare decision-making based on semantic understanding. The fundamental elements of IoT, including identification via electronic product codes, sensing through sensors to measure physiological parameters, and communication using technologies such as IPv4, IPv6, and wireless standards, collaborate to deliver comprehensive, patient-centered care by guaranteeing secure sharing and efficient management of all pertinent data(Azzawi et al., 2016) (Figure 1).

A meticulous and systematic strategy is crucial for the successful implementation of IoT in healthcare (Figure 2). First and foremost, it is critical to explicitly establish goals, such as patient monitoring and efficiency, and thoroughly assess the current infrastructure to identify any deficiencies. Next, we conduct an evaluation to identify the specific Internet of Things (IoT) solutions needed, such as sensors and wearable devices. Choosing suitable IoT technologies entails conducting thorough research on the available devices and platforms, assessing suppliers based on their dependability and support, and opting for solutions that seamlessly connect with current systems. An integration strategy includes the planning of how IoT devices will establish connections with existing systems, the management of data storage, processing, and security, and the assurance of compatibility across devices and systems(Gupta et al., 2017).

The implementation phase involves the installation and configuration of IoT devices, their integration with healthcare IT infrastructure, and the testing of their functionality(Mahajan & Gupta, 2020). It is crucial to teach healthcare personnel, which involves creating instructional resources, organizing hands-on training sessions, and offering continuous assistance. Monitoring and evaluating performance entails establishing metrics for assessing impact, consistently monitoring the system's functionality, and gathering input to improve it. The process of refining systems using performance data, strategically planning for expansion to additional areas or facilities, and consistently deploying updates and additions achieves optimization and scaling. To ensure compliance and security, it is necessary to strictly follow healthcare standards, utilize encryption and secure communication methods, and conduct regular audits. Active patient education, feedback channels, and support services ultimately enhance the success of integrating IoT devices in healthcare(Begum & Dharmarajan, 2020).

The incorporation of IoT into healthcare systems can effectively address current difficulties and enhance the quality of treatment by boosting data security, optimizing system integration, and enabling superior patient monitoring and interaction. This results in enhanced and proficient healthcare provision as the industry progresses towards improved health results and patient-focused treatment.

4.1 A Healthcare Example of an IoT Service

Remote Patient Monitoring (RPM) exemplifies the significant influence that Internet of Things (IoT) technology may have on the healthcare industry. RPM systems use IoT technology to provide uninterrupted, live monitoring of patients' health conditions from the comfort of their homes. This novel method combines diverse elements, such as wearable sensors, wireless communication networks, cloud-based data storage, and advanced analytics platforms, to improve patient care and operational efficiency (Hayes et al., 2023).

Remote Patient Monitoring (RPM) entails the utilization of wearable equipment, such as pulse oximeters, thermometers, and blood pressure monitors, to gather crucial health information, including heart rate, oxygen saturation, and body temperature. These devices transmit data wirelessly to cloud-based secure servers, where powerful algorithms and artificial intelligence evaluate it. The collected data offers practical insights, allowing healthcare providers to continuously monitor the health state of patients, identify early indications of decline, and swiftly respond without requiring in-person consultations(Mantena & Keshavjee, 2021).

The design of RPM systems allows for seamless integration of real-time monitoring with clinical decision-making processes (Figure 3). Healthcare providers consistently receive patient data, using it to assess patients' illnesses, adjust treatment plans, and make informed decisions about the need for additional medical procedures. The ability to remotely monitor patients is particularly beneficial for the management of chronic illnesses, where regular health evaluations are critical, as well as for addressing sudden health emergencies, such as infectious disease outbreaks.

A case study showcases the effectiveness of RPM in managing cancer patients who have contracted COVID-19. Amidst the epidemic, the Mayo Clinic introduced a Remote Patient Monitoring (RPM) initiative to tackle the distinct difficulties presented by the simultaneous presence of cancer and COVID-19. The program registered 200 patients, either during their COVID-19 diagnosis or after their hospital discharge. The main goals were to improve patient outcomes and reduce hospital utilization by facilitating early identification of health problems and offering prompt remedies. The RPM initiative utilized various IoT devices, such as Bluetooth-enabled sensors and tablets, to streamline the process of collecting and transmitting data. A virtual care team monitored and assessed the key health indices of patients. This strategy resulted in substantial enhancements in patient care. Specifically, the RPM program group of patients experienced a 35% reduction in hospital admissions compared to those who did not participate in the program. In addition, there was a 20% reduction in the average length of hospital stays. Furthermore, the RPM group had a decrease in the number of ICU admissions and a lower death rate(Pritchett et al., 2021).

The RPM program's success underscores its capacity to revolutionize healthcare delivery through improved patient monitoring and optimized resource allocation. Remote Patient Monitoring (RPM) improves clinical outcomes and relieves the burden on healthcare systems by providing continuous, up-to-date data and facilitating proactive care(Gordon et al., 2020). This case study highlights the broader impact of RPM as a paradigm of IoT integration in healthcare, showcasing its efficacy in handling intricate patient circumstances and providing useful perspectives for future advancements in remote monitoring technology.

5. Discussion

The incorporation of Internet of Things (IoT) technology in the healthcare industry is revolutionizing the provision of medical services by providing cutting-edge solutions for both patients and healthcare professionals. The shift is notably apparent among the different age groups and health conditions examined in this study. Internet of Things (IoT) devices specifically created for young children not only address acute health concerns but also offer continuous monitoring, which is crucial for early detection and intervention(Chu et al., 2018). The implementation of IoT in chronic care management demonstrates its ability to decrease hospital stay rates and improve patients' quality of life through real-

Table 1. Healthcare System Challenges vs. IoT Solutions

Challenges	IoT Solutions
Data Security and Confidentiality	**Enhanced Data Security**
The growing dependence on digital technologies exposes healthcare organizations to the risk of data breaches and cyberattacks, affecting patient trust and compliance.	The Internet of Things (IoT) utilizes advanced encryption and secure communication protocols to safeguard patient data from unauthorized access or breaches.
Integration of Diverse Technologies	**Seamless Technology Integration**
Healthcare settings employ a diverse array of technological instruments and software systems, frequently resulting in compatibility issues and inefficiencies.	The Internet of Things (IoT) facilitates the standardization of communication protocols, hence promoting seamless collaboration between diverse technologies and systems.
Rising Healthcare Costs	**Cost Reduction through Efficiency**
The increasing expenses and restricted availability of resources hinder the ability to receive healthcare and diminish the quality of services provided.	The Internet of Things (IoT) allows for remote monitoring and the use of data to make informed decisions, which reduces the necessity for regular in-person appointments and decreases operational expenses.
Limited Access to Medical Care	**Improved Access to Care**
Patients face difficulties accessing prompt medical care due to resources and geographical constraints.	The Internet of Things (IoT) enables the provision of telehealth services and remote monitoring, thereby ensuring that medical care is easily accessible to patients irrespective of their geographical location.
Inefficient Data Management	**Efficient Data Management**
Poor management of health data hampers informed decision-making and consistent care delivery.	Internet of Things (IoT) devices constantly gather and synchronize health data in real-time, improving data precision and accessibility for making well-informed decisions.
Delayed Care Delivery	**Faster Care Delivery**
Process inefficiencies might result in delays in delivering essential medical care.	The use of automated data processing and real-time monitoring facilitates expedited reactions and prompt interventions in medical care.

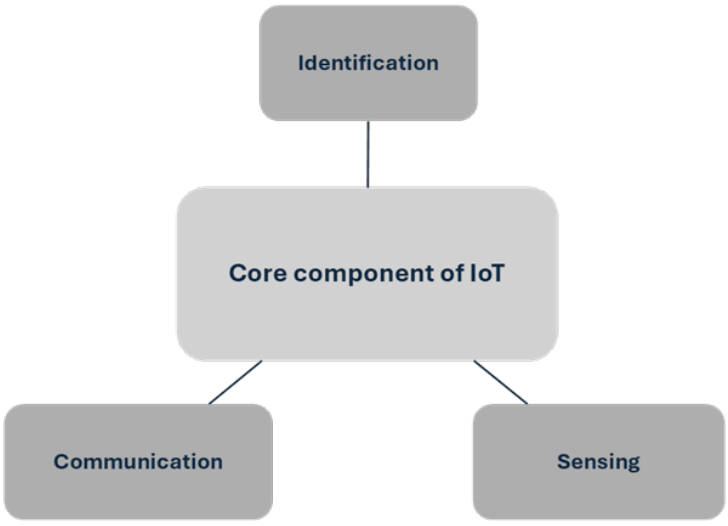

Figure 1. Core component of IoT

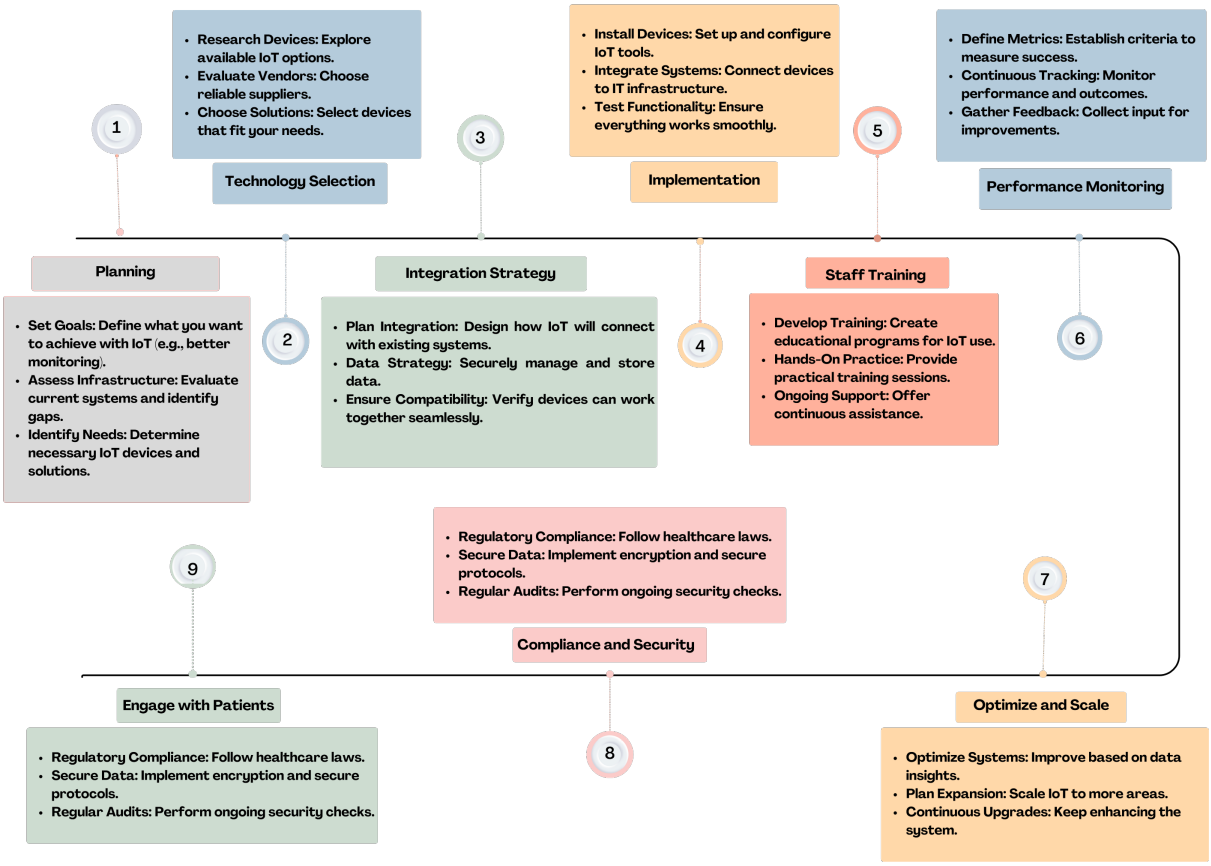

Figure 2. Step-by-Step Guide to Implementing IoT in Healthcare

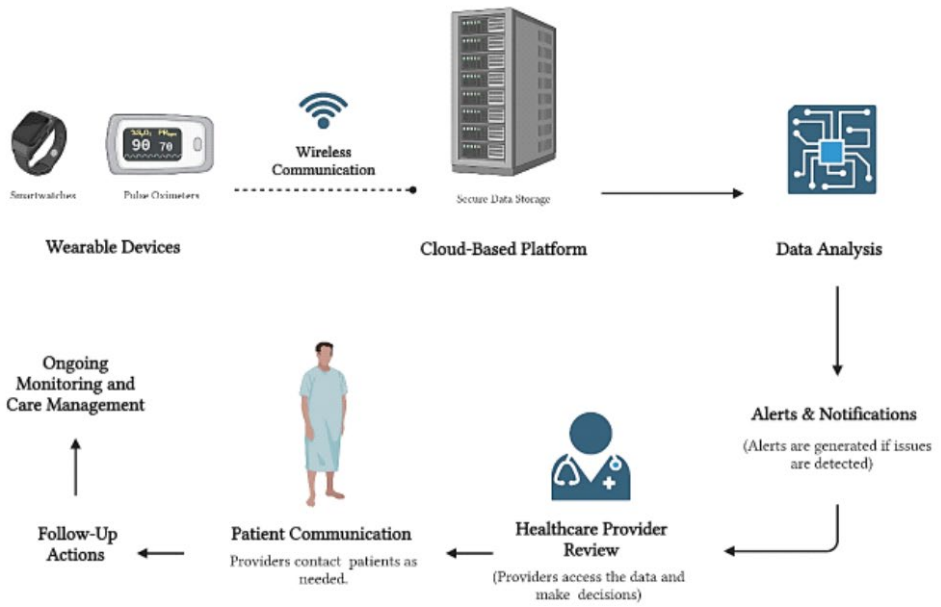

Figure 3. Remote Patient Monitoring (RPM)

time monitoring and prompt responses to health deterioration(Dadkhah et al., 2021). Furthermore, the utilization of IoT in Personal Emergency Response Systems (PERS) and Mandown systems is essential for immediately delivering emergency aid to people who are predisposed to falls or sudden health emergencies, thus improving patient safety.

The advancement of Internet of Things (IoT) technology for surgical guidance and body motion reconstruction represents a significant improvement in the field of precision medicine. These tools assist surgeons in delivering live data and improving the precision of intricate surgeries (Kuddus et al., 2022). Moreover, the utilization of Internet of Things (IoT) technology in pharmaceutical dispensers guarantees compliance with specified drug regimens, addressing the prevalent issue of managing chronic diseases. This technology not only alleviates the strain on healthcare systems but also enables patients to assume authority over their health. Nevertheless, the integration of IoT in healthcare is not devoid of obstacles. Data privacy, security, and the requirement for uniform protocols are crucial challenges that must be resolved to fully harness the promise of the Internet of Things (IoT). Ensuring strong cybersecurity measures is crucial in addressing the significant concern of data breaches and unauthorized access to sensitive health information. Moreover, the compatibility of IoT devices across various platforms continues to be a difficulty, requiring the creation of universal benchmarks to guarantee smooth integration and data sharing between devices (Ashakin et al., 2014).

Notwithstanding these difficulties, the study depicted in this article demonstrates the tangible advantages of Internet of Things (IoT) services in a healthcare environment. The example illustrates how the Internet of Things (IoT) can improve the efficiency and efficacy of healthcare delivery, resulting in improved patient outcomes and more optimal utilization of healthcare resources. The Internet of Things (IoT) offers a notable benefit to healthcare by enabling the remote monitoring of patients, delivering real-time feedback, and allowing for the modification of treatment regimens based on continuous data collection.

6. Conclusion

The incorporation of Internet of Things (IoT) technology in the healthcare sector offers a hopeful opportunity to enhance patient care, optimize healthcare delivery, and decrease healthcare expenses. The applications explored in this paper, which include pediatric care, chronic illness management, and surgical guidance, highlight the adaptability and promise of IoT in meeting various healthcare requirements. Although there are obstacles concerning data security, privacy, and standardization, the advantages of IoT in healthcare significantly surpass these worries. The future of healthcare hinges on the ongoing advancement and incorporation of Internet of Things (IoT) technology. As these technologies advance, they will gain the ability to offer personalized, immediate care to patients, enhancing results and revolutionizing the healthcare sector. To effectively harness the potential of IoT in the healthcare sector, it is imperative for policymakers, healthcare providers, and technology developers to collaborate and collectively tackle the difficulties at hand. By undertaking such initiatives, the Internet of Things (IoT) can have a pivotal impact on establishing a healthcare system that is more prompt, effective, and focused on the needs of patients.

Author contributions

M.H.R. led the conceptualization, methodology, and supervision. T.I. managed data curation and project administration. M.H.H.A. and M.S.S.S. contributed to investigation, analysis, and drafting. M.E.C. provided validation and resources, while M.R.A. supported visualization and interpretation. B.H. secured funding and reviewed the manuscript. P.K.B. and M.N. handled review, editing, and revisions. A.R.S. supervised, finalized the manuscript, and served as the corresponding author. All authors approved the final version.

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Competing financial interests

The authors have no conflict of interest.

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