IJARSCT

International Journal of Advanced Research in Science, Communication and Technology

International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal

ISSN: 2581-9429

Volume 5, Issue 1, September 2025

Impact Factor: 7.67

Review on IoT in Smart Healthcare Monitoring Systems

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Abstract: *The Internet of Things (IoT) is a rapidly evolving technology that is revolutionizing how we interact with our surroundings by connecting physical objects and sensors to the internet [37, 37]. This paper provides a detailed examination of IoT's adoption in healthcare, which is a transformative shift from a traditional, reactive healthcare model to a proactive, continuous, and coordinated one [37, 37, 39]. The review focuses on specific sensor types and communication methods, highlighting their role in enabling real-world applications like remote patient monitoring, personalized treatment strategies, and streamlined healthcare delivery. The paper also delves into the challenges and limitations associated with this technology, such as data security, interoperability, and the need for standardized protocols. By addressing these issues, healthcare providers, policymakers, and researchers can collectively harness the full potential of IoT to improve patient care, optimize resource allocation, and enhance overall healthcare efficiency.*[1].

Keywords: IoT, Healthcare, Remote monitoring, Smart Healthcare, WSN (Wireless Sensor Networks), Recognition of Radio Frequency

I. INTRODUCTION

The Internet of Things (IoT) is a revolutionary and rapidly evolving technology that connects physical objects and sensors via the internet to enable communication and data sharing [37, 37]. With the number of connected devices projected to reach over 75 billion worldwide by 2025, the healthcare industry is expected to be a major beneficiary of this growth [37, 37]. This intricate network, often termed the Internet of Medical Things (IoMT) or IoHT, is fundamentally reshaping the healthcare model from a traditional, reactive system into a proactive, continuous, and coordinated continuum of care [37, 37, 39]. This paradigm shift is particularly crucial given the challenges posed by a rapidly aging global population and the rising prevalence of chronic diseases, which have created a growing demand for cost-effective healthcare systems [37, 37, 38].

The integration of IoT in healthcare offers new opportunities for remote monitoring [37, 37], personalized treatment plans [1], and efficient healthcare delivery.[1] This technology enhances patient outcomes, streamlines operations, and empowers patients to take a more active role in their care.[1] However, the use of IoT in healthcare also brings a host of challenges and limitations, including concerns about data privacy and security, interoperability issues, and the need for standardized protocols.[1] This review paper aims to provide a comprehensive overview of the IoT healthcare landscape by examining its foundational technologies, key applications, and the challenges and opportunities that must be addressed to realize its full potential.

Potential Benefits:

The integration of IoT in healthcare offers a variety of benefits that are transforming patient care and operational efficiency. The primary advantages include:

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- **Reduced Cost of Care:** IoT can substantially reduce healthcare costs by automating routine tasks and decreasing the need for expensive interventions and hospitalizations [37, 37]. Continuous monitoring and early detection capabilities help prevent costly medical complications, which ultimately lowers overall healthcare expenses.[1]
- **Improved Patient Outcomes:** Real-time data collection and monitoring from IoT devices allow for improved response times and timely medical interventions, which can lead to better patient outcomes and enhance overall patient safety [37, 37].
- **Enhanced Patient Engagement:** IoT improves patient engagement by giving individuals greater control over their health. Wearable devices and mobile apps allow patients to track their health data and communicate more effectively with healthcare providers.[1]
- **Automation of Procedures:** The IoT makes it possible to automate healthcare procedures that previously required a significant amount of time and were prone to human error.[1] Examples include automating vital sign monitoring and medication dispensing, which reduces errors and lowers labor costs.[1]
- **Elimination of Distance Limitations:** IoT-driven solutions bring healthcare to patients rather than the other way around. This is a practical solution for the elderly and people with disabilities, allowing them to be monitored in real time from home [37, 37]. Patients in remote areas can use video conferencing with their doctors, improving their health while saving time and money.[1]

Keywords:
IoT-based healthcare is enabled by a multi-layered architecture that connects devices and services to deliver real-world applications.

Multi-layered IoT Architecture:
The architecture is typically composed of five layers [37, 37, 40]:

- **Perception Layer:** The foundational layer where physical sensors and devices collect raw data on physiological parameters, such as heart rate, temperature, and mobility [37, 37].
- **Network Layer:** This layer transmits the collected data using various communication technologies, including Bluetooth, Wi-Fi, and cellular networks [37, 37, 40].
- **Middle Wave Layer:** This layer processes and stores large volumes of data from the network layer, often linking with big data and cloud computing platforms [37, 37].
- **Application Layer:** This layer provides user-facing services and interfaces, such as mobile apps that display patient data and send alerts [37, 37].
- **Business Layer:** This layer manages the entire IoT ecosystem, providing intelligent decision-making and recommendations, such as suggesting the nearest hospital to a patient [37, 37].

Essential Sensors:
A variety of sensors are essential for collecting physiological data.[1] These include:

- **Electrocardiogram (ECG):** Detects arrhythmias and heart disease by measuring heart electrical activity.[1]
- **Pulse Oximeter:** Measures oxygen saturation and heart rate.[1]
- **Blood Pressure:** Monitors for hypertension and hypotension.[1]
- **Glucose:** Enables continuous diabetes monitoring.[1]
- **Temperature:** Detects fevers or hypothermia.[1]
- **Respiratory:** Monitors breathing disorders such as sleep apnea.[1]

Researchers are also developing advanced sensors, such as a non-invasive blood pressure sensor using micro pyramid-assisted piezoelectric film (MPF) technology [1] and a paper-based humidity sensor for respiratory monitoring.[1]
Communication and Data Processing:
Communication technologies like Bluetooth, Wi-Fi, and cellular networks are crucial for real-time data transfer [37, 37]. While Bluetooth is ideal for low-power wearables, cellular networks (4G/5G) provide broad coverage for remote

monitoring [37, 37, 41, 42]. For data processing, edge computing addresses latency by processing data locally, which is vital for time-sensitive applications [37, 37, 45, 46]. Cloud computing provides scalable storage and supports advanced analytics for large volumes of data and electronic health records (EHRs) [37, 37, 43, 44].

Key Use Cases:

- **Remote Patient Monitoring (RPM):** A central application of IoT, RPM enables healthcare providers to continuously track a patient's vital signs from a distance, which is particularly effective for managing chronic diseases [37, 37, 37].
- **Locating Systems:** Real-time locating systems (RTLS) track patients and medical resources using wearable devices or RFID tags, which enhances safety and operational efficiency [37, 37].
- **Personalized Medicine:** IoT and data analytics are enabling a shift toward personalized medicine, which tailors treatment to an individual patient's unique genetic and lifestyle factors. AI algorithms analyze real-time data to generate individualized care plans, improving treatment effectiveness [37, 37, 47].

Challenges and Advantages:

The integration of IoT in healthcare presents significant challenges that must be addressed to ensure its successful implementation. These challenges are often intertwined with the advantages the technology offers.

Challenges and Limitations:

- **Data Security and Privacy:** The collection and transmission of sensitive medical data require stringent safeguards to protect patient privacy [37, 37, 40, 50]. Many medical IoT devices lack robust security controls and are not designed with security in mind, making them vulnerable to cyberattacks.[2] The legal landscape is also complex, with a lack of clarity on who is responsible for a data breach when a device is in a patient's home.[2]
- **Interoperability and Standardization:** The lack of interoperability between devices and systems from different vendors creates data silos and inefficient data exchange [37, 37, 52]. The absence of standardized protocols makes it difficult to integrate new IoT devices with existing Electronic Health Record (EHR) systems and other healthcare platforms [37, 37, 53].
- **Quality of Service (QoS):** QoS is a critical concern for life-and-death applications, as delays in real-time patient monitoring can have catastrophic consequences.[3] Another challenge is energy efficiency, as the continuous data collection required for healthcare is power-intensive for battery-operated wearables, creating a trade-off between device functionality and operational longevity.[3]

Advantages and Future Outlook:

Despite these challenges, the advantages of IoT in healthcare, combined with emerging trends, point to a promising future. AI is expected to transform the vast data from IoT devices into actionable insights, moving healthcare from a reactive to a proactive model [37, 37, 41, 47]. AI algorithms will be used for predictive analytics to forecast future health events, enabling timely interventions.[5] AI is also becoming a core component of modern cybersecurity, enabling systems to learn a baseline of normal behavior and detect subtle anomalies that traditional methods would miss.[8] The advent of quantum computing poses a long-term threat to current encryption methods, but AI is expected to play a pivotal role in the transition to quantum-safe security by optimizing new post-quantum cryptographic (PQC) algorithms and automating the massive migration effort to new standards.[11]

To address the "black box" problem where AI's decisions are opaque, Explainable AI (XAI) is an emerging trend that aims to make these processes transparent and understandable to humans.[14] This enhances trust and improves the accuracy of threat detection. The challenge of data privacy can be addressed through federated learning, a decentralized AI approach that allows multiple organizations to collaboratively train a shared model without ever sharing their raw, private data.[17] This is particularly advantageous for healthcare, as it enables the creation of powerful global threat intelligence models while ensuring patient data remains localized and private.[17]

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