



A Comprehensive Roadmap for Transforming Healthcare from Hospital-Centric to Patient-Centric through Healthcare Internet of Things (IoT)

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Abstract

The Internet of Things (IoT) has emerged as a game-changing technology across various industries, significantly impacting the healthcare sector. This study focuses on the profound effects of IoT in healthcare, particularly in real-time monitoring and data collection facilitated by IoT-enabled systems. The integration of sensors, wearables, and medical devices provides medical professionals with vital insights into patient conditions, enabling personalized treatment plans, remote monitoring, and the timely identification of health abnormalities. This research aims to present a comprehensive roadmap for transforming healthcare from a hospital-centric to a patient-centric model through IoT. The primary objectives are to understand how healthcare IoT (HIoT) can enhance operational efficiency, enable personalized care, and facilitate remote monitoring for improved patient outcomes. To achieve these objectives, a comprehensive study of healthcare IoT technologies, including wearables, smartwatches, mobile health (m-Health), and fitness trackers, has been conducted. The study highlights how interconnected devices and data analytics enhance operational efficiency, personalized patient care, and the optimization of medical procedures. Ultimately, the comprehensive roadmap outlined for smarter and safer healthcare amenities through IoT technologies points towards a future where customized care, remote monitoring, and expedited procedures become integral components of healthcare delivery.

Keywords: Blockchain; Healthcare; Internet of things (IoT); m-Health; Road accident; Safety.

Received: 23 December 2023; Revised: 02 June 2024; Accepted: 16 June 2024.

Article type: Review article.

1. Introduction

The Internet of Things (IoT) allows physical objects to communicate and share data with each other. Over time, IoT technologies have advanced, incorporating sensors, machine learning, real-time analytics, and embedded systems.^[1] In smart hospitals, various devices are connected using fixed or wireless internet, enabling smart data collection and sharing.^[2,3] This concept extends to smart cities, cars, homes, and healthcare, bringing benefits to various aspects of our lives.^[4] For instance, the implementation of IoT in healthcare involves an array of sensors, medical devices, artificial intelligence, diagnostics, and advanced imaging tools.^[5] This comprehensive approach enhances patient care and outcomes. Both traditional and modern industries experience improved productivity and an enhanced quality of life through these IoT

devices.^[6]

IoT enables data transfer through the internet without any human intervention.^[2] The use of this technology in healthcare monitoring is experiencing significant growth during the COVID-19 pandemic.^[7] In the present day, numerous individuals are losing their lives due to the harmful consequences of misinformation regarding their health.^[8] This technology can rapidly notify the user of any health concerns by utilising sensors. The cloud is used to store all data related to COVID-19 patients, which helps in ensuring that they receive the appropriate level of attention.^[9] This technology has the capability to monitor an individual's daily activities and promptly notify them if they encounter any health issues.^[10] The need of appropriate medical equipment is crucial for the achievement of a successful medical operation.^[11] IoT exhibits a high degree of compatibility with regard to executing effective operations and evaluating the

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outcomes of these activities.^[12] The utilisation of IoT technology in the context of the COVID-19 pandemic has demonstrated advancements in the provision of healthcare services to patients.^[13] Real-time monitoring using IoT technology has the potential to effectively reduce many health issues, such as diabetes, heart failure, asthma attacks, and hypertension, ultimately leading to the preservation of human life.^[14] By utilising a smartphone, intelligent medical devices have the capability to convey essential health data to healthcare professionals.^[15] In addition, these gadgets are capable of monitoring vital health indicators such as oxygen saturation, blood pressure, body weight, and blood glucose levels.^[16]

Doctors were unable to perform real-time analysis of a patient's condition due to the absence of IoT technology in the past.^[12] This initiative has enabled healthcare facilities to serve a larger number of people at a lower cost.^[17] The use of big data and cloud computing has greatly improved the reliability and simplicity of patient-doctor communication.^[18] Consequently, there was an increased level of patient engagement in the treatment process, coupled with a reduced financial burden on the patient.^[19] In recent years, the healthcare Internet of Things (HIoT) has had a significant impact on various applications related to health and fitness management, sickness judgment, and chronic disease monitoring, *etc.*^[20] The applications of HIoT have been categorised into two primary groups, specifically facilities and solicitations, to enhance comprehension of these entities.^[21] HIoT devices may be categorised into two distinct groups: those employed in the advancement of novel medical devices and those used for monitoring and diagnosing existing conditions.^[12]

1.1 Related Work and Major Contributions

Numerous researchers have dedicated their efforts to develop HIoT powered healthcare transportation safety systems, where the use of technology has made the task easier, and accurate. IoT systems tackle emerging challenges in the medical field have the potential to greatly benefit doctors, surgeons, and patients alike. A motorist protection system based on an accelerometer was proposed by Ref. [22]. This framework utilizes Raspberry Pi (ARM11) to provide convenient access to control and event discovery. In case of an emergency, a message is promptly sent to the relevant establishments to enable them to respond quickly and effectively in order to save lives, provide assistance, and minimize harm. The proposed model is inadequate and incomplete because it only includes one element and disregards the additional essential factors. The crash avoidance system for vehicles has implemented an effective approach to identify obstacles in both the front and

blind spots.^[23] The driver is alerted to a decreasing distance between their vehicle and an obstacle through a beeper and an LED symbol. The ultrasonic sensor in a vehicle's ultrasonic system can determine whether an object is in motion or stationary. This tool is highly effective for detecting other vehicles, motorcycles, bikes, and pedestrians that may cross your path while you are driving alongside the road. The chapter utilizes a Raspberry Pi microcomputer to operate the proposed system. However, it is important to note that the Raspberry Pi microcomputer has limited performance capabilities by default. A proposal was made by Ref. [24] to integrate an alcohol detector into a reliable system for preventing vehicle collisions. This system alerts the driver to the amount of alcohol they have consumed, and displays this information on an LCD screen. A buzzer is utilized to notify the driver of their own situation and also to startle individuals nearby.^[25] A driver who is excessively drowsy will be unable to start a vehicle because their reflexes will be impaired. Ironically, this technique aims to increase the driver's self-awareness of their condition while also pressuring them to take action. While the concept is innovative, it lacks practicality.

There are several review papers published in the field of HIoT over the past few years. These reviews typically focus on various aspects of HIoT, including its applications, challenges, opportunities, and advancements in specific areas of healthcare. In a review article, Kashani *et al.*^[21] systematically identified, analyzed and categorized the existing literatures into five approaches: sensor-based, resource-based, communication-based, application-based, and security-based. It provides a comprehensive overview of IoT applications in healthcare, discussing the benefits and challenges associated with implementing IoT technologies in healthcare systems. In another review article, Pradhan *et al.*^[12] provided an up-to-date summary of potential healthcare applications of IoT-based technologies, highlighting advancements in enabling technologies, healthcare services, and applications addressing various healthcare issues. In the most recent review article, Suleski *et al.*^[26] assessed existing solutions in healthcare authentication, focusing on technologies within HIoT to provide insights into advancements and challenges in healthcare authentication systems. However, the current study can provide an updated understanding of the current state of HIoT, its challenges, and opportunities, while also offering practical insights and future research directions to advance the field. It can also contribute to the field by addressing several gaps and providing a unique perspective not covered by the existing literature. Some potential contributions are as follows:

- Detailed comparative analysis of HIoT solutions across

healthcare domains for effectiveness, complexity, and user acceptance.

- In-depth analysis of practical challenges for Real-world HIoT systems Implementations.
- Exploration of HIoT integration with 5G, blockchain, and advanced AI/ML for addressing challenges like data security and interoperability.
- Focus on empowering patients, improving engagement, and supporting personalized healthcare through HIoT.
- Identification and proposal of future research directions including enhancing device interoperability, data analytics, and cost-effective solutions.

Beside this, the paper is organized in a methodical manner, commencing with an introduction, related work and major contributions. In section 2, it navigates through the major components and amenities of Healthcare IoT. Subsequently, it explores the diverse applications of Healthcare IoT, showcasing its transformative potential in various medical settings. A compelling case study on Smart and Safe Transportation with Healthcare IoT offers a real-world illustration of its efficacy. Challenges and opportunities inherent in Healthcare IoT are discussed in section 5. Finally, the paper concludes with a concise summary and future perspectives.

2. Major components and amenities of healthcare IoT

The integration of IoT into healthcare has started a new era of medical advancements, significantly enhancing the quality and efficiency of patient care.^[27] This section explores the fundamental components and benefits that comprise HIoT. By connecting various devices such as sensors, actuators, and smartphones, HIoT systems enable the continuous collection and analysis of health data, facilitating real-time monitoring and management.^[28] The deployment of diverse communication protocols like Bluetooth, ZigBee, Wi-Fi, and 5G ensures robust connectivity.^[29] This interconnected ecosystem not only supports sophisticated data processing and cloud-based applications but also promotes patient-centered care, reducing the emphasis on traditional clinic-based treatment.^[30] Furthermore, this section examines the wide range of amenities HIoT offers from wearable devices and mobile health applications to blockchain technology and cognitive computing, showcasing how these innovations are revolutionizing healthcare delivery and management.

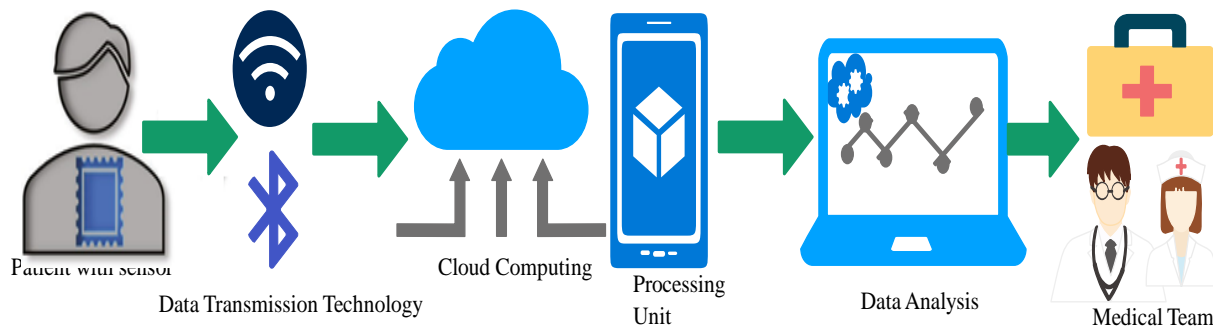


Fig. 1 Illustration of a typical healthcare IoT system.

2.1 Major Components of Healthcare IoT

HIoT has revolutionized healthcare by creating a comprehensive ecosystem where various devices like sensors, actuators, and smartphones communicate and gather data to enhance patient care.^[13] According to network needs, user satisfaction, and wireless communication ranges, HIoT networks may make use of various communication protocols such as Bluetooth, ZigBee, Wireless fidelity (Wi-Fi), 5G, *etc.* The data collected from these network devices undergoes extensive analysis and is shared with cloud servers, allowing for sophisticated applications in data classification, judgment, and planning.^[31] Smart Medical Care (SMC) systems integrated with HIoT enable continuous remote monitoring and management of patient health, leading to extensive, long-term health records review. This integration results in reduced clinical expenses and a shift towards patient-centered care, enhancing overall healthcare delivery by reducing the focus on clinic-centric treatment.^[10]

There are five main components that make up a healthcare IoT system, which are as follows: physiological sensor unit, processing unit, communication and transmission unit, storage and computing unit, data analytics and decision-making unit. Health data collected by smart medical devices is processed and sent to distant healthcare facilities or other IoT devices for further analysis. Bluetooth, Zigbee, Wifi, *etc.*, are examples of short-range communication technologies that smart healthcare devices use to communicate to other IoT devices, while Worldwide Interoperability for Microwave Access (WiMAX), Lora, 4G, 5G, *etc.*, are examples of long-range communication technologies that smart healthcare devices use to communicate to remote health centers and clouds.^[31] Fig. 1 shows the block diagram of a typical Healthcare IoT system.

2.2 Amenities of healthcare IoT

The landscape of healthcare has undergone a profound transformation assisting the novel services and concepts that tackle a broad spectrum of healthcare concerns. As the demand for healthcare continues to surge and technology advances unabatedly, a plethora of new services are seamlessly integrated on a daily basis.^[32] These elements have become intrinsic to the very fabric of the HIoT system design process. Within the field of HIoT, each service offers a diverse array of healthcare solutions as depicted in Fig. 2. However, the subsequent section delves into the particulars of the most

2.2.2 Mobile Internet of Things

Patients' health data and other physiological conditions can be tracked using mobile calculating, sensors, and cloud calculating. Efficient healthcare services, enabled by PANs, 4G, and 5G technologies, empower healthcare providers to access patient data, analyze it, and respond swiftly through mobile devices.^[37] Numerous studies have explored the utilization of mobile computing in healthcare.^[13] For instance, diabetic individuals with low blood sugar levels benefit from an m-IoT-based system for glucose monitoring.^[38] Similarly, an "AMBRO" HIoT system for fall detection and heart rate management incorporates GPS for patient localization.^[12] This system can identify irregular heart rates (60-100 beats per minute) and promptly alert the subject. Ensuring privacy and security in an m-IoT system remains crucial to safeguard user data.^[39]

2.2.3 Blockchain

In HIoT network, seamless data exchange between medical planners and healthcare professionals is pivotal.^[40] However, data fragmentation poses a significant challenge to secure data sharing. Fragmented data can lead to information gaps among healthcare providers connected to the same patient, potentially hindering effective treatment.^[41] Blockchain technology emerges as a solution to combat data disintegration by establishing data linkage across the network's repositories.^[42] There are three key pillars supporting the safe transmission of Blockchain data. Firstly, its editable yet tamper-proof "ledger" prevents data manipulation after entry. Each ledger transaction is rigorously recorded following predefined rules.^[43] Secondly, as a decentralized technology, blockchain can function simultaneously across various devices.^[44] Smart contracts further enforce data exchange agreements. These contracts manage access to blockchain-stored Electronic Medical Records (EMRs), maintaining user identities and ensuring authorized EMR access for doctors.^[45] In an article, researchers have introduced a blockchain-based application, named Healthcare Data Gateway (HDG), empowering patients with control over their medical record sharing.^[46] This approach grants patients full control over their data while adhering to stringent confidentiality protocols. Through these advancements, blockchain technology holds promise in fortifying data integrity, interoperability, and patient-centric data management within the HIoT ecosystem.

2.2.4 Ambient assisted living in natural settings

Ambient assisted living (AAL) is a specialized division of AI that utilizes IoT to provide assistance to the elderly.^[30] AAL aims to enhance the ability of the elderly to stay in their homes

for longer periods by improving safety and convenience.^[47] AAL provides real-time monitoring and assistance for individuals experiencing medical emergencies to ensure they receive human-like support.^[47] Progressive AI skills, large statistics study, machine learning, and their application in healthcare businesses make it possible.^[30] Researchers have studied three main areas of AAL: action acknowledgment, atmosphere acknowledgment, and dynamic observing. In Ref. [48], proposed health care solutions for the elderly. The writer proposed a segmental building for AAL safety, automation, and communication. RFID and NFC were the communication protocols used during the enactment. This device connects patients with healthcare providers through a closed-ring communication facility. The protocol developed from the architecture can be used to build advanced IoT-based AAL systems.^[40] The authors have developed an emergency detector to help the elderly during difficult situations and potential health crises. Carers were notified during emergencies. Assistive robots and IoT-based healthcare systems can now monitor indoor air quality.^[14] Carers receive alerts for low air quality. The proposal suggests creating a secure and adaptable platform for Ambient Assisted Living (AAL) using an Internet of Things (IoT) gateway connected to cloud computing.^[49] The gateway played a crucial role in addressing various issues related to IoT security, data storage, and interoperability.^[50]

2.2.5 Empowering Children's Health through CHI

The objective of "CHI" is to educate and empower children and parents by providing complete information regarding children's well-being. This includes a child's physical, mental, emotional, and behavioral health.^[51] The goal of CHI is to help families improve their children's health. Using HIoT, a breakthrough technology monitors and manages children's health. Within this framework, an IoT-based architecture monitors a child's mental and physical health.^[52,53] A separate app lets physicians and healthcare professionals access the data. Mobile health (m-health) applications may also track kids' diets.^[54] Additionally, this application ensures children's dietary needs are addressed. Proactive child health management is enabled via CHI's IoT integration.

2.2.6 Cognitive computing Integration with HIoT

The application of cognitive computing, which mimics the processing capabilities of the human brain, has become a fundamental aspect of contemporary computation.^[55] The integration of cognitive computing into IoT systems enables the discovery of complex patterns within large datasets.^[56] This technological advancement enhances the capabilities of sensors, allowing for the processing of healthcare data in a

seamless manner that can quickly adapt to changing environments.^[57] In a synchronized cognitive IoT network, these sensors work together with smart devices to provide efficient healthcare services.^[58] The cognitive data transmission approach proposed by Kumar *et al.* improves the efficiency of detecting, recording, and assessing patients' health data.^[59] This approach plays a crucial role in promptly disseminating vital information during emergency situations.

2.2.7 Reducing Adverse Drug Reactions through HIoT

An adverse drug reaction (ADR) may arise as an unintended consequence. This response could happen after a single dose or at the end of a treatment plan. When two different medicines are taken at the same time, this can also lead to side effects. It is important to realize that the main thing that affects antibiotic-related side effects, called ADRs, is the individual patient, not the type of drug or the illness being treated. In an ADR system based on the Internet of Things (IoT), each medicine is given a unique identity on the patient's device, such as a barcode or a unique number.^[29] Using a pharmaceutically smart information system makes it possible to figure out if a drug is safe for a patient based on how their body works. Patients' allergy data is kept in their electronic health records, which are part of the computer system. By looking at the patient's allergy profile and any other important health information, it is possible to figure out if a certain drug is right for that patient.

2.2.8 Advancing community health through localized healthcare systems

Community-based healthcare monitoring focuses on developing healthcare systems that are specifically designed

for smaller geographic areas, such as dedicated hospitals or apartment complexes.^[12] This approach enables thorough health monitoring in the community. Interconnected community networks allow for collaborative healthcare services by uniting multiple networks.^[60] A remote healthcare observation system was introduced, utilizing the capabilities of IoT.^[61] Network connections were secured through the implementation of strong authentication and authorization techniques.^[62] A study introduced the idea of a "virtual hospital" in local medical networks, allowing medical care to be provided to people who are physically separated.^[63] The user promotes for a resident health network and proposes a four-level organizational framework for patients' medical records.^[64] The framework enables local wellness centres to provide personalized medical advice to residents using their specific medical histories and needs.

3. Applications of Healthcare IoT

There are a variety of IoT- based applications that can be developed using the HIoT services/ concepts as illustrated in Fig. 4. Researchers in these fields have come up with a slew of ideas aimed at improving all of us. Applications, on the other hand, focus on end users, whereas concepts cater more to developers. The affordability and accessibility of wearable sensors, portable gadgets, and medical devices have significantly improved due to the rapid advancement of IoT technology. The collection of patient data, diagnosis of diseases, and monitoring of their health can be feasibly accomplished.

3.1 ECG Detection and Monitoring

The depolarization of the atria and ventricles represent the

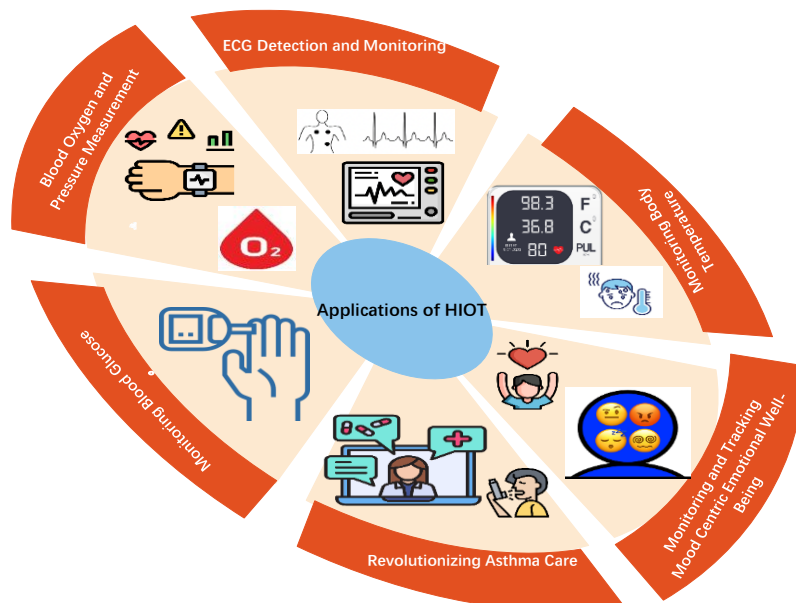


Fig. 4 Varieties of IoT- based applications in HIoT services.

electrical activity of the heart in an electrocardiogram (ECG). In addition to providing information about the heart's fundamental rhythms, an ECG also serves as an indicator for a variety of abnormalities. This includes abnormalities such as arrhythmia, a shortened QT interval, myocardial ischemia and other conditions. The IoT- founded ECG observing scheme projected in Ref. [65] consists of devices that receive data wirelessly. In order to perceive cardiac irregularities in actual time, it used an automated search method. It was proposed in Ref. [66] that an ECG monitoring system be integrated into a t- shirt. The ECG data was collected using a bio potential chip. Bluetooth was used to deliver the recorded data to the end users. A mobile app could be used to view the ECG data that had been recorded. 5.2 mW is the minimum amount of power required to run the proposed system. After integrating big data analytics into an IoT system, real- time monitoring can be achieved. Notably, the authors in Ref. [67] have attempted to address the problem of high power ingesting with a wearable ECG nursing scheme. Compressive sensing, a new method they've proposed, has the potential to reduce power consumption while also enhancing ECG monitoring performance. It has been reported that an IoT- founded drop recognition and ECG observing scheme using a bank of cloud founded server and a movable submission has been developed. Elderly patients can be monitored in real time using this system's ECG and accelerometer data, which are constantly checked.

3.2 Monitoring blood glucose

Diabetes is a condition with consistently high blood glucose levels. The three most common forms of diabetes are type 1, type 2, and gestational diabetes.^[68] The most common method of identifying diabetes is through fingerpicking and blood glucose analysis.^[69] Recent advancements in IoT technology have greatly improved blood glucose monitoring devices, making them noninvasive, comfortable, convenient, and safe for users. Wearable sensors were connected to healthcare providers using IPv6 connectivity. A glove has been created by researchers that utilizes a Raspberry Pi camera and a visible laser beam to measure blood glucose levels. Diabetic condition of patients was determined through analysis of fingertip images. Researchers used IoT architecture and a double moving average algorithm to measure blood glucose levels.^[70]

3.3 Monitoring body temperature

It is often used in diagnostic procedures to determine if a patient is in a state of homeostasis. Certain illnesses, such as trauma and sepsis, can lead to changes in body temperature,

which may serve as a warning sign. Recent advancements in IoT-based technologies have addressed this problem in various ways. A 3D printed UWB localizer with infrared sensors embedded in the tympanic membrane was developed to monitor the body's core temperature. The device was equipped with a wireless instrument module and a data dispensation component.^[71] Fever is not affected by physical activity in this situation. Gunawan has developed an IoT temperature monitoring system using Arduino and Raspberry Pi. The temperature data could be accessed through a desktop computer or a mobile phone, and it was stored in a database.^[72] Studies have utilized lightweight and wearable sensors to monitor infants' body temperatures in real time. The device can alert parents when the temperature exceeds a specific limit.

3.4 Blood oxygen and pressure measurement

Pulse oximetry is a crucial parameter in healthcare analysis as it allows for noninvasive measurement of oxygen saturation. The integration of IoT technology into pulse oximetry has shown potential for use in the healthcare industry. A noninvasive tissue oximeter was proposed into measure body fluid oxygen levels, heart rate, and heart rate constraints.^[73] A medicinal interference pronouncement was made using the recorded data. An alarm system is triggered when the oxygen saturation falls below a specific level to alert the patient. The Blynk server facilitated the connection between a pulse oximeter and a WLAN router in the system. Von Chong *et al.* propose a multispectral sensor that mitigates the negative effects of a single LED.^[74]

Blood pressure (BP) measurement is crucial for diagnostics of individual health. This monitoring has been transformed with the integration of IoT and other detecting skills. Cuffless wearable devices have been suggested in a study^[75] to measure both systolic and diastolic body fluid pressure at the same time, and data were stored on the internet. The effectiveness and accuracy of this method were assessed on a group of 60 individuals. Guntha has developed an IoT-based blood pressure measurement system that utilizes cloud computing and fog computing. A long-term real-time monitoring system has been implemented. Information can be saved on the device for future use. Deep learning CNN models were employed to assess systolic and diastolic blood pressure in further training. An ECG signal and a photoplethysmogram (PPG) were used to measure blood pressure in a study.^[76] A microcontroller module was used to calculate BP and the data was sent to cloud storage.

3.5 Revolutionizing asthma care

Asthma is a long-term condition that can cause breathing

difficulties. Asthma causes the airways to swell, resulting in a narrowing of the passages. Breathlessness, coughing, ribcage discomfort and shortage of breath are all symptoms of this. Asthma attacks can occur unexpectedly, necessitating the use of an inhaler or nebulizer as the sole means of rescue. Recent years have seen an influx of IoT- based systems for asthma monitoring.^[77] Asthma patients could benefit from a smart sensor-based HIoT solution that could monitor their respiratory rate. For diagnostic and monitoring purposes, the health data was stored in a cloud server that was accessible to the caregivers. It was Raji's idea to use an LM35 hotness measuring device to monitor the breathing degree and send an alarm. Monitoring the hotness of the air breathed in and breathed out helped achieve this. The health center has successfully implemented an advanced IoT-based asthma monitoring system, which allows real-time tracking of patient's respiration data and displays it over the internet.^[78] This sophisticated system is designed to automatically alert patients when their respiratory data reaches a critical threshold, sending a notification directly to their smartphones. Moreover, utilizing machine learning and big data analytics, the system can assess the patient's environment and guide them away from locations that may negatively impact their well-being.^[79] The integration of cloud computing further enhances the system's ability to process and analyze vast amounts of data efficiently. Researchers have identified several features that could enhance this IoT-based asthma monitoring system in the future, ensuring even more comprehensive and responsive care for asthma patients. These potential enhancements include advanced predictive analytics, personalized health recommendations, integration with other health monitoring devices, and improved user interfaces for easier patient interaction.^[10] With these improvements, the system holds promise for significantly improving the management and quality of life for individuals with asthma.

3.6 Monitoring and tracking mood centric emotional well-being

Emotional health can be maintained by tracking one's mood, which can be used to monitor one's emotional well-being. The ability to keep tabs on one's own emotional state is one of the many benefits of self-monitoring.^[80] A CNN net was applied to assess and classify an individual's temperament into six classes: pleased, enthusiastic, unhappy, peaceful, distraught and annoyed, rendering to temperament mining approach.^[81] An interactive system called "Meezaj" was used in a similar way to measure practical-time mood.^[12] Using the app, policymakers were able to identify the factors significant to the happiness in an educational institute. Now, thanks to a

progressive machine knowledge procedure, heartbeat rate can be used to detect stress before it occurs. As an added benefit, patients' stress levels can be relayed to the system via communication. An IoT-based system that prevents an accident can be designed by analyzing the stress condition of a person. There are four negative emotions/ moods that researchers have projected a wearable device can approximate.^[82] This smart system determines whether or not the driver is in a subconscious state by investigating the dissimilarity in these sentiments. The dc motor of the vehicle is stopped once the driver is in a trance- like state.

4. Case study for smart and safe transportation with healthcare IoT

Before the invention of the wheel, early humans lived in isolation from other tribes and societies. They were only able to commute to work if it involved a brief walk. The invention of the wheel marked a significant turning point in the early development of mankind. Over time, prehistoric humans evolved into well-mannered and civilised individuals, and during this process, the design of the wheel was also refined. The number of registered motor vehicles in Delhi has increased from 11,996,000 to 12,500,000 between 2020 and 2022.^[83] This rise has resulted in an increase in the number of accidents and, consequently, the number of casualties. According to the India Spends 2015 report on traffic-related deaths, motor vehicle accidents accounted for 83% of all road traffic-associated deaths in 2015.^[84] According to the Delhi Traffic Police, there were a total of 4720 road crashes in Delhi in 2022, in which 4273 people were injured and 1239 people lost their lives.^[85] This is a significant increase from the past data.

Fatal car accidents can result from various factors, notably including seat belt non-compliance, driving while intoxicated (DWI), and drowsy driving. Seat belts, pivotal for preventing fatalities and injuries, remain underutilized due to forgetfulness or misconceptions.^[84] DWI impairs driving ability and judgment akin to drowsy driving, which mirrors the risks of intoxicated operation. Beyond these, additional contributors to accidents comprise aggressive driving, wherein recklessness jeopardizes road safety. Distracted driving, encompassing activities like texting or eating, diverts attention from the road. Unfavourable weather conditions further exacerbate risks by impairing visibility and control.^[86] The three major accident catalysts: seat belt non-compliance, DWI, and drowsy driving. Counteracting these factors is pivotal for saving lives. The following outcomes are anticipated as a result of this study plan:

- **Enhanced Seat Belt Compliance:** The engine activation will

be contingent on securely fastened seat belts, promoting a safety-first approach.

- **Preventing Intoxicated Driving:** Integration of a gas sensor will ensure the engine starts only when the driver is sober, curbing the risk of drunk driving.
- **Reducing Drowsy Driving:** Incorporation of eye-blink feelers will monitor driver alertness, minimizing the chances of drowsy driving-related accidents.
- **Collision Avoidance:** Utilization of proximity sensors will provide real-time obstacle detection, aiding in collision prevention and safer manoeuvring.
- **Efficient Post-Crash Response:** In the aftermath of a collision, a GPS-based alert system will accurately locate the vehicle, promptly notifying relevant parties for timely assistance. Vibration sensors will instantaneously detect accidents.

Through these measures, the plan aims to significantly elevate road safety standards, curbing accidents, and creating a more secure driving environment for all. HIoT technology has advanced smart and safe transportation systems by enabling precise monitoring of vehicle and passenger conditions. These IoT-based systems facilitate accurate tracking and management of transportation networks, ensuring that sensitive data such as passenger information and vehicle diagnostics remain secure and confidential. With cloud storage, transportation data is easily accessible to authorized personnel while maintaining security, benefiting both operators and passengers through transparent communication regarding travel safety and vehicle status.^[87] The efficiency and reliability of HIoT in transportation have also transformed

vehicles into smart vehicles, allowing meticulous recording and sharing of data with transportation authority's.^[88] This creates a secure environment for passenger safety and efficient transport management, ensuring timely and safe travel.

5. Challenges and opportunities of healthcare IoT

The integration of IoT technologies into healthcare presents several challenges, such as data security, interoperability, and regulatory compliance, it also offers significant opportunities for enhancing patient care, operational efficiency, and patient engagement. Addressing these challenges through robust security measures, standardization, and cost-effective solutions can help in transformative implementing and advancements of HIoT systems. In this section, the multiple opportunities of HIoT to revolutionize patient care and operational efficiency are also discussed.

5.1 Challenges of HIoT

The adoption of HIoT comes with some significant challenges that must be addressed to fully realize its benefits. These challenges are data security, privacy concerns, interoperability issues, data management, high costs, complexity of implementation, regulatory and compliance requirements.^[89] Overcoming these challenges is essential to implement the transformative power of HIoT while ensuring the protection and efficacy of healthcare delivery systems. Fig. 5 depicts the challenges of HIoT.

5.1.1 Data security and privacy

The integration of IoT devices in healthcare results in the

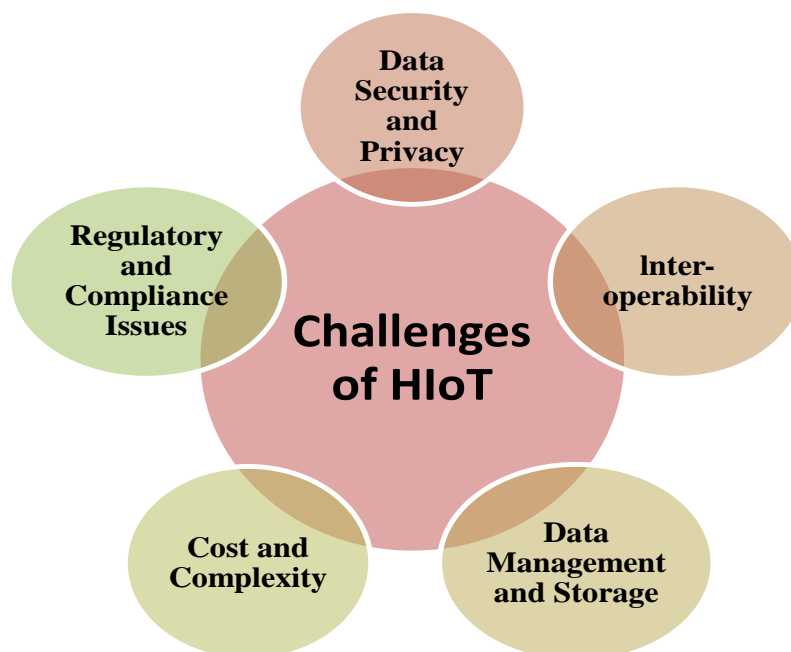


Fig. 5 Challenges of Healthcare IoT.

collection of vast amounts of sensitive health data which introduces substantial security and privacy risks. Unauthorized access, data breaches, and cyber-attacks pose serious threats, potentially exposing personal health information to malicious entities.^[90] To minimize these risks and protect patient data, it is imperative to implement robust security measures. This includes utilizing advanced encryption techniques to protect data at rest and in transit, employing secure communication protocols to ensure data integrity and confidentiality, and conducting regular security audits to identify and address vulnerabilities proactively.^[91] These comprehensive security strategies are crucial to maintaining the trust and safety of patients in the increasingly digital landscape of healthcare.

5.1.2 Interoperability

In Health IoT, a significant challenge is the diverse array of standards and protocols employed by different IoT devices and systems. This lack of uniformity leads to substantial interoperability issues, creating barriers to continuous data exchange and integration across various healthcare platforms.^[12] The fragmentation caused by these disparate standards means that devices and systems often cannot communicate effectively with one another, impeding the cohesive functioning of HIoT ecosystems. To address this, there is a need to develop and implement universal standards and protocols. Such standardization would facilitate smooth interoperability and integration, ensuring that diverse HIoT devices and systems can communicate and function well together, improving the efficiency and effectiveness of healthcare services.^[92]

5.1.3 Data management and storage

Managing the constant flow of large data from many IoT devices is a big challenge for storing and organizing information. Maintaining the precision, coherence, and availability of this data emerges as a major concern. To address this challenge, it becomes imperative to deploy streamlined data management and storage mechanisms adept at handling the sheer magnitude of information generated by HIoT systems. Embracing cutting-edge solutions such as cloud computing and utilizing sophisticated big data analytics frameworks becomes indispensable in navigating through this sea of data. By employing these strategies, healthcare enterprises can not only manage the data deluge effectively but also unlock actionable insights crucial for informed decision-making and improved patient outcomes.

5.1.4 Cost and complexity

Implementing HIoT systems demands considerable financial investment and intricate logistical planning, including the installation of sensors, devices, networking infrastructure, and associated technologies.^[93] Moreover, the ongoing maintenance and upgrades required can strain resources. However, developing cost-effective solutions and scalable technologies, these challenges can be minimized.^[94] Thus, HIoT systems can become more attainable and enduring, ensuring their long-term viability and contribution to healthcare innovation.

5.1.5 Regulatory and compliance issues

The healthcare industry is highly regulated, and compliance with various standards, such as HIPAA (Health Insurance Portability and Accountability Act) law is mandatory.^[95] It ensures patient information stays private and secure. Meeting these standards can be complex and time-consuming because there are many rules to understand and follow. It is important to ensure that HIoT systems adhere to relevant regulations and standards.^[96] This ensures their successful integration and acceptance within the healthcare sector.

5.2 Opportunities of HIoT

In the dynamic landscape of healthcare, the integration of HIoT brings multiple opportunities to revolutionize patient care and operational efficiency. This subsection explores how HIoT can make patients healthier, make healthcare work better, and bring new ideas. By utilizing the power of IoT technologies, healthcare providers stand at the brink of a transformative era, where data-driven decision-making and patient empowerment converge to redefine the healthcare services. Fig. 6 depicts the opportunities of HIoT.

5.2.1 Enhanced patient care

HIoT empowers healthcare providers with the ability to continuously monitor patient's health conditions in real-time, enabling prompt data collection and analysis. This proactive approach facilitates the early detection of potential health issues, paving the way for personalized treatment plans and timely interventions, all of which contribute to better patient outcomes.^[97] Through the utilization of IoT technologies, healthcare professionals can deliver care that is both proactive and personalized, ultimately elevating the quality of patient care to new heights.^[27]

5.2.2 Operational efficiency

IoT technologies revolutionize how healthcare facilities manage their resources, from tracking inventory and assets to managing patient flow. By implementing HIoT systems, healthcare facilities can maximize resource usage, minimize

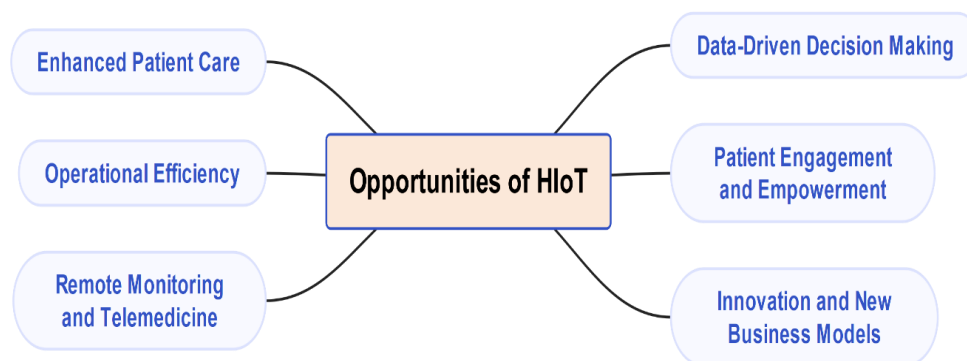


Fig. 6 Opportunities of Healthcare IoT.

waste, and enhance overall operational efficiency.^[6] This means better allocation of resources where they are needed most, smoother workflows throughout the facility, and ultimately, cost savings for healthcare providers.

5.2.3 Remote monitoring and telemedicine

HIoT enables healthcare providers to remotely monitor patient's health conditions which is a significant advantage for managing chronic diseases and post-operative recovery.^[10] This technology allows medical professionals to track patient's well-being without requiring them to be physically present. By facilitating remote monitoring and telemedicine services, HIoT enhances access to healthcare while diminishing the necessity for frequent hospital visits.^[98]

5.2.4 Data-driven decision making

The data collected by HIoT devices provides valuable insights into patient's health trends and patterns. Advanced data analytics and machine learning algorithms can be applied to this data to support clinical decision-making.^[99] Utilizing data analytics within HIoT systems holds the promise of revolutionizing medical decision-making, resulting in enhanced patient outcomes and elevated healthcare standards. With access to real-time data insights, healthcare professionals can make more informed and precise clinical judgments. This means they can modify treatments more effectively, leading to improved outcomes for patients.^[100] Ultimately, the integration of data analytics into HIoT systems serves as a foundation for advancing healthcare quality and driving continuous improvement in patient well-being.

5.2.5 Patient engagement and empowerment

HIoT devices, such as wearable health monitors and mobile health applications, empower patients to actively engage in their health management. Patients can monitor their health metrics, set wellness goals, and receive personalized health Recommendations.^[33] When patients are more involved and empowered in managing their health, they are more likely to stick to their treatment plans, healthier lifestyles, and improved overall health outcomes.

5.2.6 Innovation and new business models

The adoption of HIoT technologies opens up opportunities for innovation and the development of new business models in healthcare. This brings an exciting opportunity for startups and technology firms to pioneer inventive IoT-driven healthcare solutions, driving growth and competition in the industry.^[101] Embracing this innovation in HIoT lead to the development of cutting-edge healthcare technologies and services, enhancing the overall healthcare ecosystem.^[102]

6. Conclusion and future perspectives

This study provides a comprehensive analysis of Healthcare IoT (HIoT) technologies, exploring their components, current applications, challenges, and opportunities. HIoT has revolutionized healthcare by enabling continuous monitoring, personalized treatment, and remote diagnostics, leading to a paradigm shift from a hospital-centric to a patient-centric approach. The integration of IoT in healthcare has facilitated real-time monitoring and diagnostics, offering improved patient outcomes and operational efficiencies. Despite significant challenges such as data security, interoperability, data management, high costs, complexity, and regulatory compliance, the potential benefits of HIoT are substantial. The forthcoming years will witness a significant impact of these challenges on research and development. Several key developments and trends are expected to shape the landscape of HIoT. Advanced data analytics and artificial intelligence (AI) will play a crucial role in the future of HIoT, providing deeper insights into patient data and enabling predictive diagnostics, personalized treatment plans, and more precise clinical decision-making. Enhanced machine learning algorithms and AI-driven analytics will revolutionize how healthcare providers analyze and utilize patient data, leading to better health outcomes. Improving interoperability standards is crucial for continuous data exchange in HIoT, enhancing healthcare efficiency and effectiveness. Future systems must incorporate robust security measures, including advanced encryption and secure communication protocols, to protect growing volumes of sensitive health data. Cost-effective, scalable solutions driven by innovations in sensor technology, cloud computing, and big data analytics will

facilitate widespread adoption of HIoT. Evolving regulatory frameworks will ensure compliance while promoting innovation. Patient empowerment through wearable monitors and mobile health apps will improve adherence to treatment plans, and the ongoing evolution of HIoT will drive innovation and new business models in healthcare. In conclusion, the future of Healthcare IoT is promising, with numerous opportunities to revolutionize patient care, improve operational efficiency, and foster innovation. By addressing current challenges and embracing emerging trends, HIoT can significantly enhance the quality of healthcare delivery and patient outcomes. Researchers and developers will play a critical role in advancing HIoT technologies, driving forward the next wave of healthcare innovation.

Conflict of Interest

There is no conflict of interest.

Supporting Information

Not applicable.

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