Enhancing Quality of Life Through IoT-Enabled Healthcare Monitoring : A Comprehensive Review

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Abstract:
The Internet of Things (IoT) has become a pivotal component in advancing innovative applications across various sectors, including smart cities, smart homes, education, healthcare, transportation, and defense. Among these, IoT's role in healthcare stands out for its transformative potential, particularly in enhancing patient care through secure, real-time remote monitoring systems. These technologies not only improve the quality of life for patients but also optimize healthcare delivery.

This review delves into the most recent trends in IoT-based healthcare monitoring systems, highlighting their growing significance. The discussion centers on the benefits of integrating IoT into healthcare, emphasizing aspects such as system effectiveness, efficiency, data protection, privacy, security, and continuous monitoring. By conducting a thorough literature review, this paper compares various IoT-based healthcare systems, analyzing their strengths and limitations in different contexts.

Moreover, the review explores the use of wireless and wearable sensor technologies in IoT monitoring systems, offering a detailed classification of sensors utilized in healthcare applications. It also addresses the critical challenges and unresolved issues related to security, privacy, and Quality of Service (QoS) in IoT healthcare systems.

In conclusion, the paper presents recommendations and suggestions for future research and development in IoT healthcare applications, with a focus on emerging technological trends. These insights aim to guide the ongoing evolution of IoT in healthcare, ensuring it meets the growing demands of the industry while safeguarding patient privacy and security.

Keywords: IoT; IoWT; healthcare; monitoring; remote

Introduction

The Internet of Things (IoT) was a concept introduced by Kevin Ashton in 1999. It refers to connecting everyday objects to the internet, allowing them to communicate and share data as part of a global network. IoT has emerged from advanced research in information and communications technology and has the potential to improve the quality of life, especially in urban areas. As the global population continues to grow rapidly and chronic diseases become more common, there's an increasing need for cost-effective healthcare systems that can efficiently manage and deliver a variety of medical services while keeping costs down.

Recently, IoT has become a major focus in the development of healthcare monitoring systems. These systems are designed to track people's health in real time by connecting different devices and services through the internet. This allows for the collection, sharing, monitoring, storing, and analysis of health data. IoT is a new way of connecting physical objects in smart applications like smart cities, smart homes, and smart healthcare, enabling remote control and monitoring.

Using sensor networks on the human body can greatly help in diagnosing and monitoring health conditions, with the added benefit of accessing this information from anywhere in the world at any time. This is especially useful for patients who might have trouble getting to a hospital. For example, they can use video calls to consult with doctors, saving time and money. Patients can also use IoT technology to track their health on their phones.

As IoT technology advances, it is expected to lead to more personalized treatment, improving patient outcomes while reducing healthcare costs. With IoT, doctors can monitor patients remotely and manage appointments more efficiently. Patients can also enhance their home healthcare, reducing the need for frequent doctor visits and unnecessary medical treatments, which can improve the quality of care and reduce overall healthcare costs.

IoT holds great promise for the future of healthcare. Soon, we may have health-monitoring systems that can be used from home, streamlining hospital processes. IoT sensors will need to be widely used to continuously monitor the body and environment, which will help track the management of chronic diseases and rehabilitation progress. In the future, virtual consultations for remote medical care will benefit from IoT's ability to efficiently connect data from multiple locations.

However, most current IoT implementations are still in the early stages and focus on deploying and configuring technology in different contexts. These practices are not yet widespread. Therefore, this paper aims to review existing research on designing and implementing IoT-based healthcare monitoring systems that improve quality of life. These systems rely on IoT devices and sensors to connect patients with the most suitable healthcare providers.

The main goal of this research paper is to provide a detailed overview of IoT-based healthcare monitoring systems, making it easier for future researchers, academics, and scientists to understand the current state of these systems and develop solutions and

improvements. The paper provides a general overview of IoT-based healthcare monitoring systems, including their benefits, significance, and a review of existing literature. It also discusses wearable technology in healthcare from an IoT perspective, classifies healthcare monitoring sensors, and addresses security and protocol challenges in IoT healthcare systems. The paper also suggests solutions to overcome these challenges and issues in the future.
The paper is organized into eight sections: Section 2 discusses IoT-based healthcare systems and their applications, and the importance of IoT in healthcare. Section 3 reviews recent studies related to this topic. Section 4 covers wearable technology and sensors in healthcare monitoring. Section 5 focuses on security and protocols for IoT healthcare systems. Section 6 discusses the challenges and open issues in IoT healthcare. Section 7 provides suggestions and recommendations, and Section 8 concludes the review.

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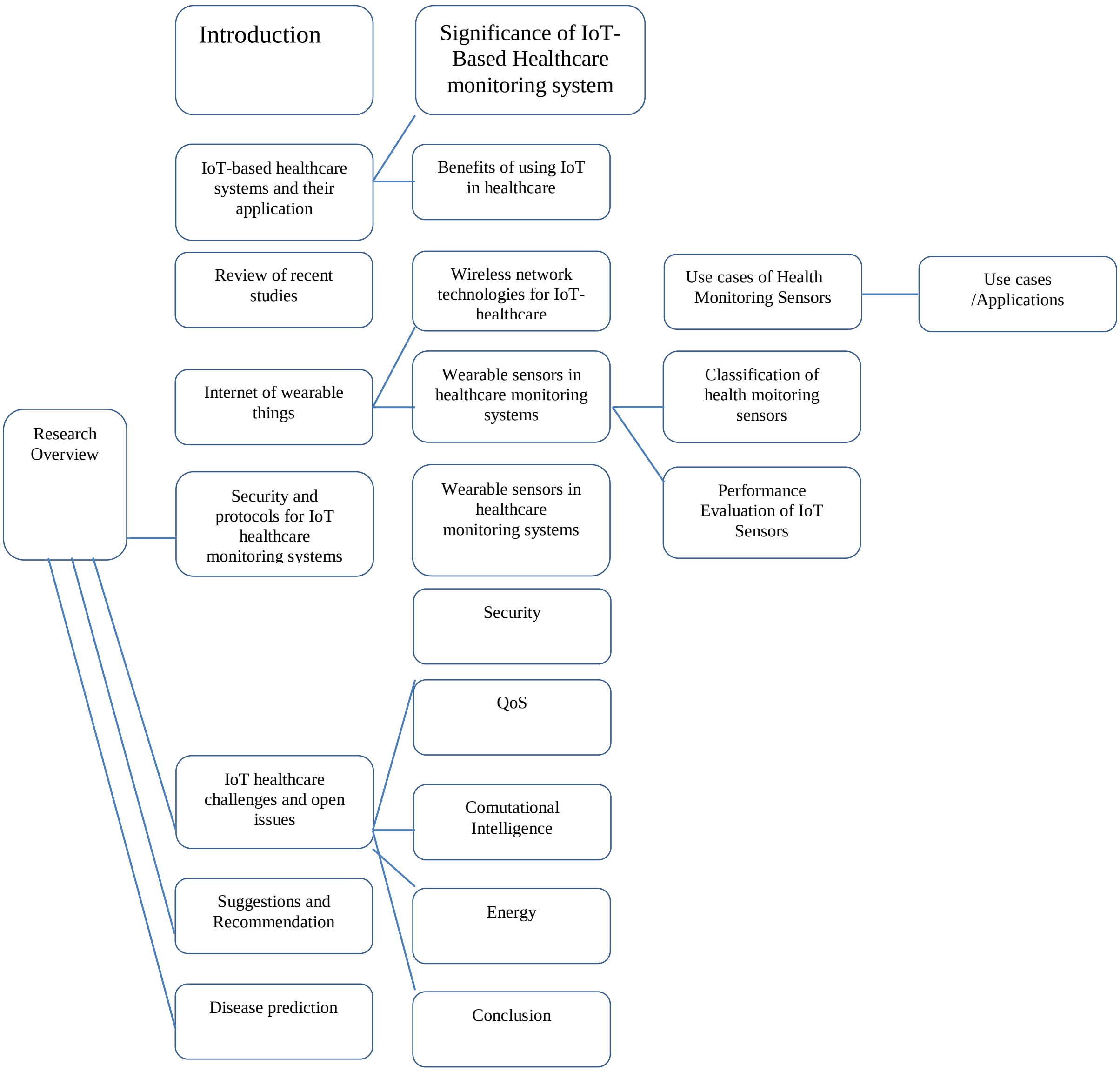

Figure 1. Research overview.

1. IoT-Based Healthcare Systems and Their Applications

IoT-based healthcare systems offer various ways to make life easier, particularly in the following areas:

1. Remote Healthcare: IoT technology enables healthcare to reach patients wherever they are. Sensors securely gather health data, which is then analyzed by algorithms before being sent to healthcare professionals for further guidance.

2. Real-Time Monitoring: Non-invasive IoT sensors continuously monitor health metrics like vital signs. The data collected is managed and stored in the cloud, allowing for real-time analysis and easy access.

3. Preventive Care: IoT systems can detect early signs of health issues by analyzing sensor data. This helps in alerting family members and tracking health trends, making early intervention possible.

2.1. The Importance of IoT-Based Healthcare-Monitoring Systems

The development of IoT-based monitoring systems for healthcare is gaining significant attention from researchers and medical professionals. As the number of elderly and chronically ill patients increases, traditional hospital-based care is becoming less effective. IoT offers a practical solution by enabling real-time monitoring of health conditions, especially for the elderly. With smart technologies, these systems can gather vital data, monitor emergencies, and ensure timely responses.

2.2 Benefits of Using IoT in Healthcare

The IoT is revolutionizing healthcare, bringing about profound changes in how devices, apps, and people interact to deliver healthcare solutions. Some key benefits include:

1. Lowering Healthcare Costs: Automation through IoT reduces the need for manual processes, saving time and reducing errors.
2. Minimizing Human Error: IoT systems improve accuracy by minimizing the chances of mistakes in medical procedures.
3. Overcoming Distance Barriers: IoT enables remote monitoring and consultation, making healthcare accessible even in remote areas.
4. Reducing Paperwork: Digital record-keeping through IoT simplifies data management and reduces the burden of paperwork.
5. Early Detection of Chronic Diseases: IoT allows for continuous monitoring, which can lead to the early diagnosis of chronic conditions.

6. Better Medication Management: IoT can help track medication schedules and ensure that patients adhere to their treatment plans.
7. Timely Medical Care: IoT systems can alert healthcare providers to emergencies, ensuring prompt medical attention.
8. Improved Treatment Outcomes: By providing accurate and timely data, IoT systems help in devising more effective treatment plans.

2. Review of Recent Related Studies

The healthcare sector encompasses many different components, from hospitals and clinics to pharmaceutical companies and insurance providers. This section reviews recent research on IoT-based healthcare-monitoring systems, summarizing various studies and their findings.

1. Wearable Devices: Wu et al. developed a wearable device that monitors body temperature, heart rate, and other vital signs, transmitting data wirelessly for analysis.
2. Intelligent Monitoring Systems: Islam et al. created a system that monitors not only patient vital signs but also environmental factors in hospital rooms, with a high success rate in data accuracy.
3. Mobile Health Monitoring: Al-Sheik and Ameen proposed a system using mobile phones to monitor vital signs remotely, though it faces challenges with long-distance communication.
4. Android-Based Systems: Hamim et al. introduced an Android app for monitoring health metrics like heart rate and body temperature, with data stored in the cloud for easy access by doctors.
5. Real-Time Monitoring: Swaroop et al. developed a system that monitors vital signs in real-time, transmitting data via various communication methods like Wi-Fi and GSM.
6. Obesity Monitoring: Gupta designed a system to monitor health metrics in obese patients, sending data to healthcare providers for remote analysis.
7. Student Health Monitoring: Souri et al. suggested a system for monitoring student health, using classifiers to predict health issues based on collected data.
8. Smart Medical Kits: Acharya and Patil developed a smart medical kit for real-time data collection and analysis, aimed at reducing the need for frequent doctor visits.
9. Data Processing Systems: Raj proposed a system for managing Big Data in healthcare, using machine learning models for accurate data processing.
10. Healthcare Models: Kishor and Chakraborty compared various machine learning algorithms to develop a healthcare model with high accuracy in diagnosing common diseases.
11. Cloud-Based Monitoring: Gera et al. focused on a cloud-based system that integrates various healthcare services, streamlining workflows and improving decision-making.
12. Fall Detection Systems: SoonHyeong et al. designed a system to detect falls and other abnormal movements, using blockchain technology to secure patient data.
13. Alzheimer's Monitoring: Piyush et al. developed a system to monitor daily activities in Alzheimer’s patients, aiming to provide better care and support.
14. Security-Enhanced Systems: Hashim et al. presented a system with multiple sensors and enhanced security features to monitor vital signs and alert medical professionals in case of abnormalities.

Aims and Contributions	Methodology	Hardware/Software	Features	Evaluation	Protocol	Limitations	Reference
A patient health-monitoring system built on IoT, connected to the Cloud Talk platform.	Software development life cycle (SDLC)	LM35, SEN-11574, MAX30102, BMP 180	Temperature, SpO2 level, BP, pulse rate	-	IEEE 802.11	Minimal contribution to medical care administration	Gera et al. [6]
Small wearable sensor patch assessing physiological signals	Raspberry Pi 3 as a fixed gateway, BLE module for transmission	AD8232, PPG, Si7051, RFD77101, Raspberry Pi 3	ECG, HR, BT, BP	-	MQTT	Range and bandwidth limitations	Wu, Wu [16]
Real-time IoT system monitoring patients' vital signs and environmental conditions	ESP32 gathering, processing, and uploading sensor data to the cloud	LM35, Heartbeat Sensor Module, DHT11, MQ-9, MQ-135, ESP32	BT, HR, CO, CO2, humidity	-	HTTP	System is big, lacking vital sensors for epidemic use	Islam, Rahaman [17]
IoT healthcare-monitoring system using mobile phones	Arduino Uno for sensor data collection, Wi-Fi transmission to the cloud	Max30102, AD8232, LM35, NodeMCU, Arduino	HR, SpO2, ECG, BT	-	IEEE 802.11	Uses two microcontrollers, limited Wi-Fi range	Al-Sheikh [19]
IoT-based remote health-monitoring system	Arduino UNO for sensor data processing, Raspberry Pi 3 for cloud upload	LM35, HR Sensor Module, GSR sensor, Arduino, Raspberry Pi 3	HR, BT	-	IEEE 802.11	Large due to dual microcontrollers	Hamim, Paul [19]
Healthcare system communicating data via BLE, GSM, and Wi-Fi	Raspberry Pi 3, BLE adaptor, USB GSM module	DS18B20, Sunrom BP/HR monitor	HR, BT, BP	-	MQTT, BLE, GSM	Accuracy depends on sensor quality	Swaroop, Chandu [20]

IoT system for monitoring the health of obese adults	MCU with a built-in keyboard and LCD for patient data	MAX30100, LM35, wrist BP and pulse rate monitor, Atmega 328, keypad, ESP8266	BP, BT, pulse rate, SpO2	-	IEEE 802.11	Two microcontrollers, Wi-Fi not ideal for long range	Gupta, Parikh [21]
IoT-based system monitoring vital signs, aiding diagnoses	Raspberry Pi with MCP3008, HRM-2511E	HR, BP, BT	-	IEEE 802.11	Wi-Fi not preferred for long-range applications	Alamsyah, Ikhlayel [22]	
Real-time system to track patients' conditions	Sensors connected to ESP32 for cloud processing	LM35, AD8232, MAX30100, BP sensor	Temperature, HR, ECG, BP, SpO2	-	IEEE 802.11	Needs evaluation, testing, and reorganization	Sangeethalakshmi et al. [23]
IoT-enabled vital-sign-monitoring system	Sensors transmit indicators to a controller via BSN	ECG electrodes, pulse oximeter, NIBP, STM32F103xC, BLE 4.0 module	HR, SpO2, temperature, BP, ECG	-	Wi-Fi/802.11, BLE	Not suitable for long-range communication	Sahu, Atulkar [24]

NodeMCU-Based Platforms: Mostafa et al. proposed a platform using NodeMCU to monitor heart rate and oxygen levels, with data displayed on both local and mobile devices.
Sleep Apnea Monitoring: Dhruba et al. created a simple application to monitor sleep apnea, successfully detecting the condition in test subjects.
Saline Monitoring Systems: Kshirsagar et al. suggested a system to monitor and control saline infusion rates, though it focuses on a single purpose.
Ubidots IoT Platform: Tiwari et al. developed a remote monitoring system using NodeMCU and the Ubidots platform, allowing for continuous monitoring of vital signs.
This comprehensive review highlights the progress and potential of IoT in healthcare, offering valuable insights for future research and development in this field.

Vaneeta et al. [38] developed an IoT-based system to monitor vital health parameters like temperature, blood pressure (BP), heart rate (HR), and blood oxygen levels (SpO2). This system is especially beneficial for rural areas, as it allows local clinics to share patient health data with larger hospitals. The IoT system can alert doctors if a patient's health deviates from normal values. The system's accuracy is close to commercial health-monitoring devices, with maximum relative errors of 2.89% for HR, 3.03% for body temperature, and 1.05% for SpO2. By leveraging fast internet and cloud storage, this system makes it easy for doctors to access real- time and historical health data, potentially aiding in early diagnosis and treatment of COVID-19.

Khan et al. [39] created an IoT health-monitoring system using Arduino to track body temperature, heart rate, and SpO2. Data is sent to an app via Bluetooth and displayed on an LCD panel, giving patients quick insights into their health. This system is particularly useful for managing chronic conditions like asthma, COPD, diabetes, and for monitoring COVID-19 patients and the elderly.

Another system, presented by the authors of [40], focuses on monitoring ECG for cardiac patients. It uses a network of sensors to gather ECG data, which is then processed and stored in the cloud via Wi-Fi. The system employs linear regression to analyze the ECG data, ensuring accurate monitoring. This system is valuable for early detection of cardiac issues by analyzing ECG signal patterns.

The paper also highlights various IoT-based health-monitoring systems, noting their benefits for patients and medical professionals. Most systems rely on embedded technologies like Arduino, Raspberry Pi, and NodeMCU to provide real-time monitoring. However, existing systems often overlook important factors like psychological and rehabilitative aspects of patient care.

The paper identifies several gaps in current IoT health-monitoring systems:

1. Limited integration with a wide range of devices.
2. Potential vulnerabilities in data security.
3. Complex systems with many disconnected components.
4. The need to enhance practitioners' ability to bridge these gaps for improved safety.
5. The challenge of adapting systems to human variability and identifying new gaps during system changes.

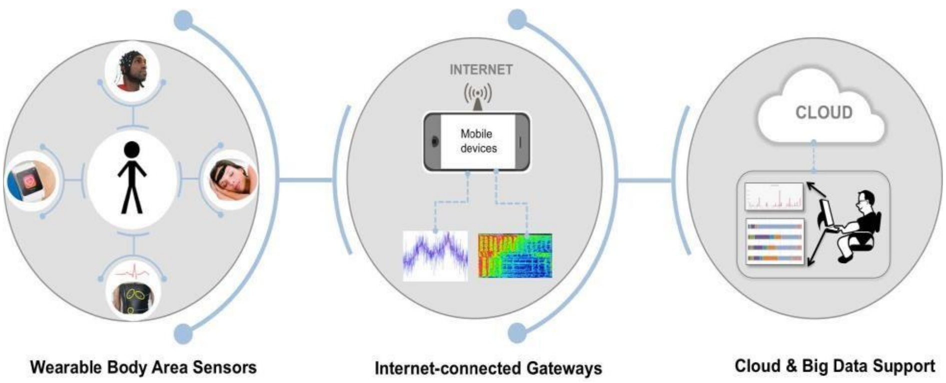

Figure 2. Architectural elements of IoWT [42].

3. The Internet of Wearable Things

The Internet of Wearable Things (IoWT) is also discussed as an emerging technology aimed at improving daily life by monitoring

health through wearable devices. The IoWT collects data that can be integrated into medical systems, allowing remote monitoring of patients. The architecture of IoWT consists of a Wireless Body Area Network (WBAN) that gathers health data, a gateway connected to the internet, and cloud storage for further analysis.

This technology has the potential to revolutionize healthcare by enabling automated telehealth solutions.

4.1. Wireless Network Technologies for IoT Healthcare

Remote healthcare monitoring is made possible through various wireless network technologies. Key IoT advancements, like RFID, Bluetooth Low Energy (BLE), Wi-Fi, Zigbee, and low-power wide area network (LPWAN) technologies such as LoRa and SigFox, play a vital role in the growth and deployment of IoT. These technologies improve device connections to the Internet and enhance the performance of IoT applications.

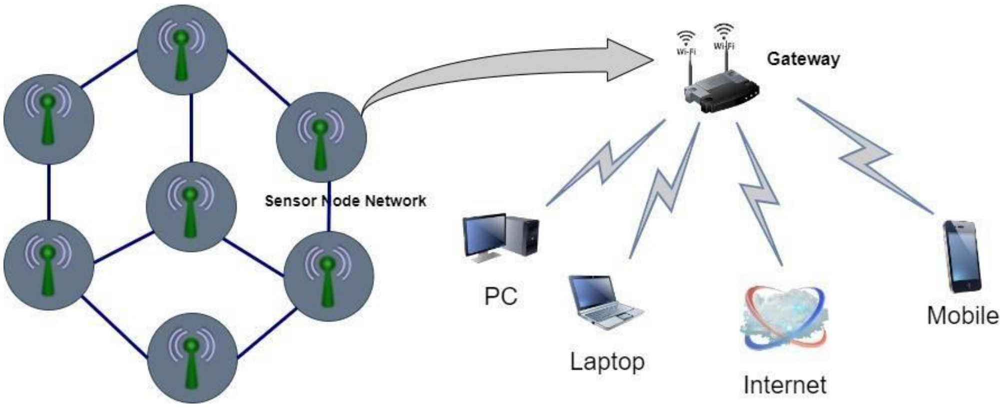

Figure 3. Relationship of WSN to IoT [46].

BLE, LoRa, and Zigbee are types of wireless sensor network technologies, while RFID is commonly used for tracking and identifying
items. BLE allows data to be shared between different mobile devices. Communication methods can differ in range, with LoRa, SigFox, and Wi-Fi supporting long-range communication, while Bluetooth, RFID, and Zigbee are better suited for short-range communication. The development of new communication protocols tailored for IoT devices, like LoRaWAN, NB-IoT, and Sigfox, is expected to increase the use of these technologies, allowing for more widespread remote monitoring.A key part of IoT is the Wireless Sensor Network (WSN). IoT enables the connection of various devices to the Internet, facilitating human-computer and machine-to- machine communication. When combined with WSN, IoT supports seamless communication between machines. Figure 3 illustrates how IoT architecture integrates with WSN, where sensor nodes communicate with a gateway in a separate network. Multiple devices connect to the gateway via Wi-Fi or the Internet, ensuring smooth interoperability. [46]

In the study referenced in [24], researchers examined current wireless applications used in connected healthcare facilities to understand how data is transmitted over short distances. They developed a system for mobile medical care within families, which includes an Android mobile client, data transmission capabilities, and a system server. The study demonstrates the potential for wireless data transfer. Sensors on medical equipment can gather important health data from family members, such as ECG, BP, SpO2, respiration, and sleep patterns.

This data is then uploaded to a back-end Web server using a wireless network, Bluetooth, or Wi-Fi. The MySQL database server handles data storage, processing, and analysis. Family members can easily monitor their loved one's health using a smartphone or tablet, viewing data through icons or text. This allows for early intervention and ongoing healthcare management, helping to prevent serious health issues.

4.2. Wearable Sensors in Healthcare-Monitoring Systems

Wearable devices are increasingly used in healthcare to monitor patients' activities and physiological functions in real-time. These devices typically include one or more sensor nodes, each equipped with a radio transceiver, a low-speed processing unit, and small memory. The sensors can track various parameters such as SpO2, BP, temperature, electrodermal activity (EDA), ECG, electromyography, HR, and RR.

Wearable devices can communicate with smartphones and other devices using technologies like Bluetooth, infrared, near-field communication (NFC), RFID, Wi-Fi, and Zigbee. This enables remote diagnosis and monitoring, which is crucial for healthcare. The IoT plays a significant role in healthcare by facilitating the identification and treatment of illnesses. With body sensor networks, data can be accessed from anywhere in the world.

One wearable sensor device developed by Vedaei can monitor and analyze patients' actions. It uses IoT technology to measure social distancing, helping prevent COVID-19 transmission. The system monitors BP, SpO2, cough rate, and temperature daily through three layers: IoT sensors, machine learning algorithms, and smartphone apps. This framework allows users to maintain a safe distance and regularly update their health status. The study also presented a Radio Frequency (RF) distance-monitoring system, applicable in both indoor and outdoor environments, which was tested under various environmental conditions to assess its effectiveness in preventing COVID-19 spread.

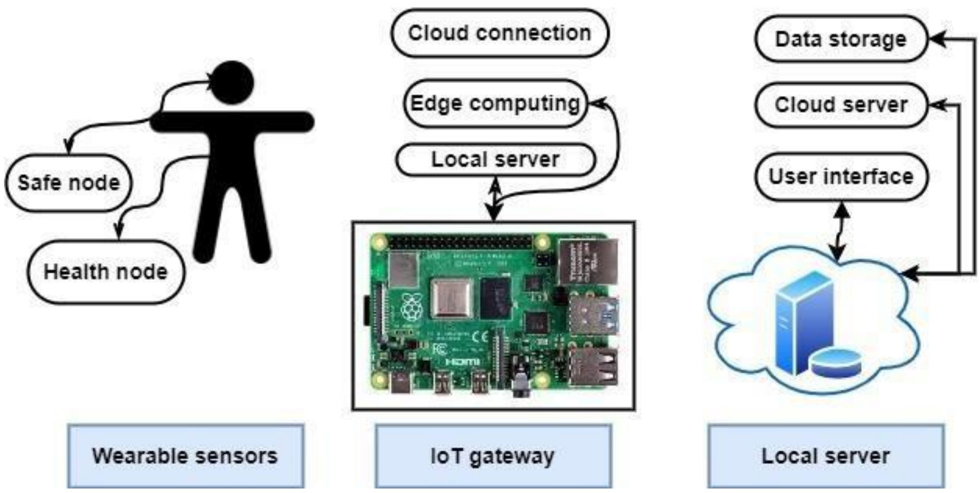

Figure 4. Healthcare-monitoring system using wearable sensor [49].

Another study [49] introduced an IoT-connected wearable sensor network system designed for health and safety in industrial outdoor
Workplaces. Wearable sensors worn by workers collect physiological and environmental data, which is transmitted to system operators and employees for monitoring and analysis. Data from multiple workers can be sent through a LoRa network to a gateway, which integrates a Bluetooth-based medical signal-detecting network with a heterogeneous IoT platform. The study details the design and hardware of the sensor nodes, the gateway, and the cloud application, showcasing a heterogeneous wearable IoT device sensor network system for health and safety. Figure 4 illustrates this system.

4.2.1. Use Cases of Health-Monitoring Sensors

Medical healthcare research today heavily focuses on the integration of healthcare systems with the Internet of Things (IoT). This integration is vital because it harnesses modern technology to save lives. IoT-based healthcare systems typically operate through three main phases: data collection, data processing, and data evaluation. Among these, the data collection phase is crucial, as it involves gathering accurate and timely information from various sources, often using sensors. The more precise the data collected, the more reliable the results.

Sensors in IoT-based healthcare systems do more than just collect data—they also play a role in ongoing monitoring and post- monitoring tasks. Examples of sensors used in this context include those that measure blood pressure, body temperature, pulse oximetry, and blood glucose levels. These sensors are essential in today's fast-growing IoT environment for collecting patients' biomedical data. High-quality data from these sensors ensure the effective development of healthcare-monitoring systems, utilizing advanced techniques like signal processing, data fusion, and analytics. Sensors that monitor heart rate, body temperature, and other vital signs are particularly valuable for early disease detection and diagnosis.

Health-monitoring sensors are used in many medical applications, including monitoring hemoglobin levels, molecular diagnostics, diagnosing albumin-related diseases, detecting heart rates, measuring blood oxygen saturation, monitoring respiration rates, and detecting conditions like anemia and Alzheimer's disease.

Wearable sensors have become increasingly popular, especially IoT-assisted wearables, which are now widely used in various fields, including healthcare. These wearables are highly user-friendly, contributing to their widespread adoption. The IoT has significantly impacted healthcare by linking various technologies to generate data for monitoring and analysis.

Here are some real-time use cases for IoT-based sensors in healthcare:

1. Heart Rate Detection/Cardiac Monitoring Systems:
   IoT-based healthcare-monitoring systems are often used for cardiac monitoring. They collect and measure heart rate data, transmitting it through various stages to a gateway and cloud server. These systems support real-time decision-making for managing cardiac conditions and predicting related diseases.
2. Body Temperature Measurement:
   During the COVID-19 pandemic, IoT-based smart health-monitoring devices equipped with

sensors became vital for monitoring body temperature, pulse, and oxygen saturation. These systems, often linked to mobile apps, allowed for continuous health monitoring.

3. Activity Recognition:
   Many wearable devices, such as fitness trackers, include activity recognition capabilities. These devices often use sensitive 3D accelerometers to track physical activity, making them popular for fitness and health monitoring.
4. Blood-Glucose Monitoring and Hemoglobin Concentration:
   The Internet of Medical Things (IoMT) includes devices like heart rate sensors and blood-glucose monitors, forming diabetic-focused wearable body sensor networks (WBSN) that monitor patients' glucose levels.
5. Respiration Rate Detection and Monitoring:
   Advanced sensors are used to monitor breathing patterns, helping keep track of the respiratory system's health. Bio- impedance sensors are one example of such technology.
6. Sleep Monitoring:
   Wearable devices can track sleep patterns by monitoring heart rate, pulse rate, SpO2 levels, and breathing. These measurements help users adjust their sleep routines for a healthier lifestyle.
7. Alzheimer’s Disease Monitoring and Anemia Detection:
   Monitoring Alzheimer’s disease requires careful handling, as diagnosing this condition when a patient is alone is challenging. Sensors can help manage the complexities involved in monitoring Alzheimer’s and anemia.
8. Molecular Diagnostics and Clinical Diagnosis:
   Recent advancements in biosensors and implantable devices have made healthcare applications more accessible and less risky. These technologies are being used for patient-friendly diagnostics and therapies, particularly in diagnosing albumin- related diseases.
9. Blood-Oxygen Saturation Detection:
   Monitoring blood oxygen levels is crucial, especially following surgeries like cardiothoracic procedures. Sensors that measure SpO2 provide continuous data on oxygen saturation in the blood, which is essential for ongoing patient care.
10. Health-monitoring sensors have shown their versatility in various applications and are expected to continue playing a significant role in diagnosing and managing different diseases. With the integration of cloud technology, geographic information systems, and mobile devices, sensor-based data collection and monitoring have become more flexible and efficient, allowing for remote data sharing and communication.
11. Classification of Health-Monitoring Sensors
    Advancements in wireless communication, medical sensor technology, and data collection methods now make it possible to remotely monitor health using wearable devices. These sensors and wearables can be incorporated into various accessories like clothing, wristbands, glasses, socks, hats, and shoes, or integrated with devices like smartphones, headphones, and wristwatches.
12. Pawan Singh [75] categorized medical sensors into two main types: contact sensors (those worn on the body) and non-contact sensors (peripheral devices). Contact sensors are further divided into monitoring and therapeutic sub-categories, while non- contact sensors are categorized into three sub-groups. Each sub-group is classified based on its specific use.

Figure 5 provides an overview of the classification of health-monitoring sensors with examples of their applications.

4.2.2.In summary, health-monitoring sensors are classified into:
Contact Sensors (On-body):
These sensors are attached to the body to monitor physiological behaviors, chemical levels, and optical measurements. They are also used for therapy-related monitoring, such as medication administration and emergency response.

Non-Contact Sensors (Peripheral):
These sensors are used for monitoring fitness and wellness, behavior, and rehabilitation. Each type of sensor plays a specific role in tracking different health-related factors.

These sensors are integral to modern healthcare, providing continuous monitoring and enabling early intervention in case of health issues.

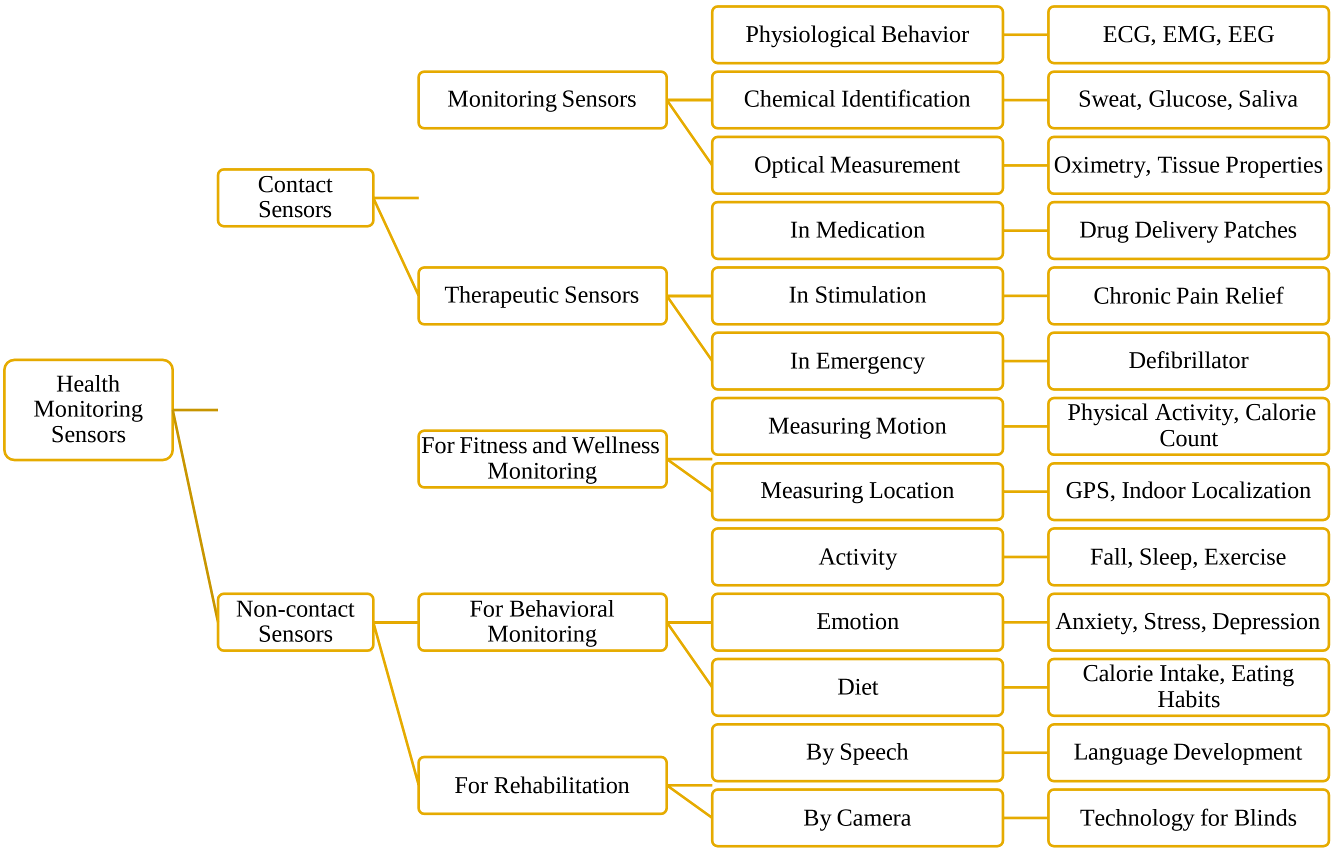

Figure 5: Classification of Health-Monitoring Sensors

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Medical sensors and wearable devices have a wide range of applications that can significantly benefit healthcare. Some of the key uses include:

Monitoring vital signs in hospitals.
Supporting aging individuals, both at home and while mobile.
Assisting people with motor and sensory impairments.
Conducting large-scale medical and behavioral research in various settings.

To better understand the performance of health-monitoring sensors, we've grouped them based on their most common applications. These categories are further detailed in the following sections. Figure 6 presents a variety of wearable sensors used in different research projects and integrated into IoT healthcare systems.
This version maintains the original intent while simplifying the language for clarity.

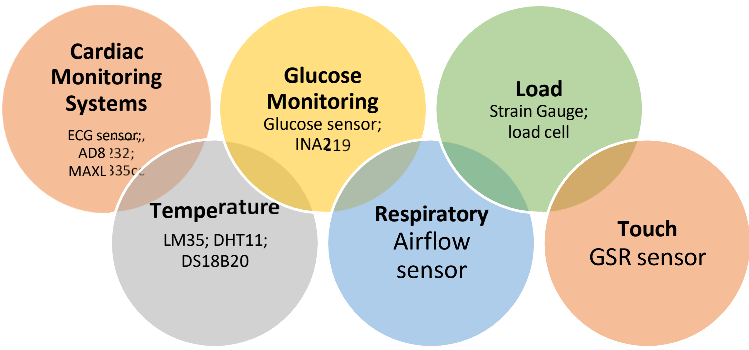

Figure 6. Various application of use cases and IoT sensors for healthcare monitoring [62,77–82].

4.1.1. Performance Evaluation of IoT Sensors

In any healthcare monitoring system, sensors are like the brain and heart of the operation, so they need to be reliable and effective. Ideal sensors should be small, quiet, accurate, and have minimal delays in data transmission. They should also be energy-efficient and perform well overall. For wearable sensors, which are often compact, accuracy and reliability are crucial since doctors rely on this data for making decisions. Medical-grade sensors, although accurate, can be bulky and require specialized handling [51].

Additionally, IoT-based healthcare applications need robust security measures to protect sensitive data. Security protocols are available, but they must be continuously updated to protect against new threats. Ensuring data privacy and system integrity remains a significant challenge.

Security and Protocols for IoT Healthcare-Monitoring Systems

With the rise of IoT in healthcare, new security risks have emerged. Medical data are highly sensitive, often containing personal information like social security numbers. IoT devices that collect and share this data are vulnerable to various security threats, including unauthorized access and data breaches [83]. These vulnerabilities arise due to issues with availability, confidentiality, and data integrity.

To address these security concerns, IoT healthcare solutions use a combination of software and hardware to monitor and regulate patient data. However, these solutions are often targeted by cyber-attacks, exploiting flaws in device security. Many existing security measures are inadequate, and there is a need for stronger, more advanced security protocols to protect sensitive medical information [85,86].

Potential solutions for improving security include using secure networks like the Onion Router (TOR) for data transfer, employing various authentication methods (e.g., fingerprints, passwords), and integrating technologies such as blockchain and artificial intelligence to detect anomalies and enhance security [87,88].

As IoT technology evolves, protocols such as CoAP, MQTT, XMPP, and others are being developed to connect devices and manage communication effectively. These protocols play a key role in applications like telehealth, medication management, and chronic disease monitoring [88].

IoT Healthcare Challenges and Open Issues

While IoT has the potential to revolutionize healthcare, several challenges remain in creating efficient and secure data- collecting systems. Key issues include:

Security: Protecting sensitive health data from breaches and unauthorized access.
Performance: Ensuring that IoT systems operate efficiently and reliably.
Computational Intelligence: Using advanced algorithms to analyze and interpret health data.
Integration: Seamlessly combining IoT devices with existing healthcare systems.
Energy: Managing power consumption to prolong device battery life.
Disease Prediction: Enhancing the accuracy of predicting and diagnosing diseases.

These challenges are crucial to address for the successful implementation of IoT in healthcare. (see Figure 7).

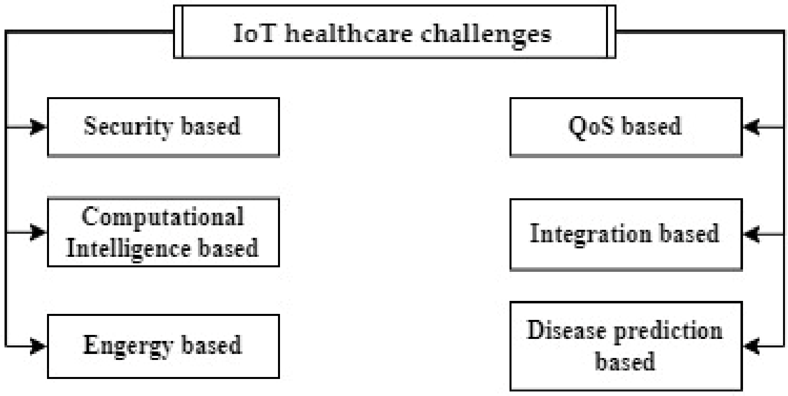

Figure 7. IoT healthcare challenges and open issues.

4. Security-Based: Privacy and Protection

Maintaining the privacy and security of medical data is a major concern. Digital records stored in the cloud are vulnerable to hacking, which can expose sensitive patient information. Key issues include user authentication, data ownership, and data protection policies [21,30,91].

To address these challenges, IoT systems must integrate strong security protocols at every level. This includes securing sensors, devices, and communication channels to ensure that personal health data remains confidential and protected. Although many health IoT applications incorporate security features such as encryption and authentication, keeping up with the latest security measures is crucial [92].

Privacy protection measures should empower users to control who can access their data. Compliance with regulations like HIPAA and the EU's GDPR helps address these concerns. However, there is a need for ongoing evaluation of how data is used, especially regarding secondary uses beyond initial permissions [11,94].

To ensure data security, information must be encrypted during transmission and processing. Cryptographic methods can help maintain user anonymity and data integrity [91,95,96].

QoS-Based: Performance, Stability, and Costs

Quality of Service (QoS) varies depending on the application but is essential for maintaining data integrity. Key performance metrics include latency, which is the time required to transfer data between devices [97].

QoS must be monitored across all IoT components, from personal devices to healthcare cloud services. Issues such as memory leaks, data transmission delays, and energy consumption must be addressed. Continuous data collection can drain battery life, leading to connectivity issues [11].

To manage these challenges, developing energy-efficient solutions and improving battery technology are essential. Additionally, reducing the cost of medical devices and improving their performance can enhance user satisfaction and accessibility [99,100].

Computational Intelligence-Based

Computational intelligence is crucial for IoT-based healthcare systems, though it is still developing. These systems rely on edge devices for data processing, which can be limited by resource constraints [11,101].

Advancing computational intelligence will enhance data analysis and system efficiency, making healthcare monitoring more effective.

Integration-Based

Integration involves connecting existing devices with new technologies to improve data accuracy and system expansion. IoT systems should integrate with technologies such as cloud computing and SDN to enhance their capabilities and improve data processing [11,102].

Effective integration can significantly benefit healthcare monitoring systems by improving communication and data handling.

Energy-Based

IoT healthcare devices often have limited battery life and consume energy even in low-power modes. Efficient power management is critical for continuous monitoring. Solutions include developing low-power communication technologies and energy-efficient hardware [99,103].

Research in activity-aware energy models and context-aware sampling can help optimize power usage and extend device operation.

Disease-Prediction-Based

IoT can accelerate early disease detection and improve patient care. Future systems will focus on predicting diseases at an early stage, enhancing treatment effectiveness, and reducing medical costs. Developing cost- effective, independent monitoring systems that alert patients early is a key goal [100,104,105].

Suggestions and Recommendations

To advance wearable healthcare devices, they must be user-friendly, adaptable, and secure. Integrating IoT with technologies like AI, fog computing, and Big Data can enhance healthcare monitoring and diagnosis. Future systems should combine these technologies to optimize health management and improve system functionality.

Conclusions

The IoT has significant potential to enhance medical care by reducing costs and improving efficiency and accuracy. This work aims to provide a comprehensive overview of IoT-based healthcare systems, including recent research, benefits, and challenges. Future research will focus on integrating new technologies and improving disease prediction capabilities.

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