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Internet of Medical Things: Architecture, Applications and Challenges

Sangeetha C P[1], Swathi Shabu[2], Althaf Ashraf[3]

[1,2,3]Electronics and Communication Department, KMEA Engineering College, Ernakulam, India
[1]scp.ec@kmeacollege.ac.in

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Abstract

The Internet of Medical Things (IoMT) is a state-of-the-art paradigm that revolutionizes healthcare by fusing the strength of medical devices, sensors, and networks with Internet of Things (IoT) technology. By offering real-time data gathering, analysis, and networking, IoMT is positioned to alter the healthcare sector. This will ultimately improve patient care, improve diagnostics, and boost the effectiveness of healthcare systems. This article describes the idea of IoMT, applications, and its architecture while highlighting both its potential advantages and limitations for the healthcare ecosystem.

Keywords

IoMT, healthcare, sensors

1. Introduction

A network of connected medical equipment and sensors known as the IoMT collects transmits, and exchanges health-related data quickly and securely. These gadgets, which are always producing a huge amount of patient data, can be worn by patients, built into medical equipment, or used in healthcare institutions. Through ongoing monitoring and data-driven insights, IoMT has the potential to provide tailored and remote healthcare, disease prevention, and early detection. Healthcare professionals may make wise decisions, customize treatments, and enhance patient outcomes by utilizing IoMT technologies.

Figure 1 shows ECG-monitoring based IoMT with different levels of operation. IoMT has a wide range of applications that have the potential to change numerous facets of healthcare delivery. Figure 2 shows IoMT applications in medical domain.

Remote Patient Monitoring: IoMT makes it possible to continuously check on patients' vital signs, underlying illnesses, and post-surgery recovery from a distance. By using this method, a patient can avoid frequent hospital appointments, patients feel more comfortable, and early diagnosis of potential health problems can be identified.

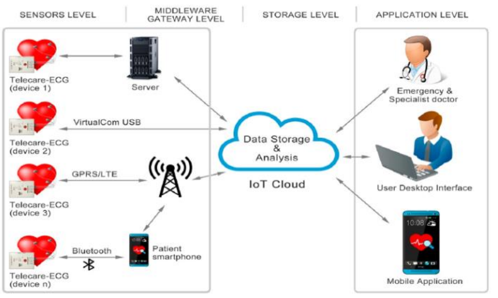


Figure 1. Example of ECG based IoMT

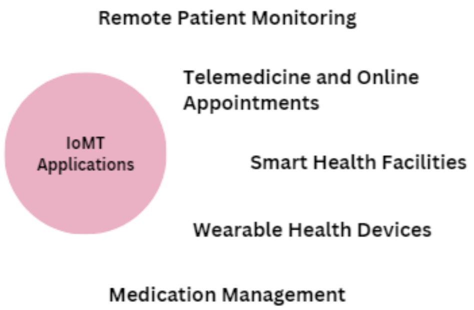


Figure 2. IoMT Applications

Telemedicine and Online Appointments: IoMT enables online consultations between patients and medical specialists thereby eradicating distance obstacles and bringing medical knowledge to neglected and remote places.

Smart Health Facilities: IoMT can be used in clinics and hospitals to improve resource management, track medical equipment, and guarantee adherence to safety standards, which results in overall increase of operational effectiveness.

Wearable Health Devices: IoMT-enabled consumer wearables like fitness trackers and smart watches provide users with insightful health information and encourage proactive wellness management.

Management: IoMT-enabled smart pill dispensers and medication tracking devices can increase medication adherence and lower medication errors, especially in aged patients who have complicated drug regimens. With the power of the Internet, medical devices, sensors, and IoMT, the healthcare industry is transforming tremendously. IoMT's primary mechanism of operation involves attaching numerous medical applications and devices to computer networks, facilitating easy data collection, transmission, and analysis [2]. The major functionalities of IoMT are:

Data gathering and transmission: IoMT works by connecting different medical apps and devices via computer networks. Direct communication with medical staff is made possible by these gadgets, which streamline data collection. Medical staff members utilize computers to collect patient health information from implanted or external portable equipment, such as pacemakers and infusion pumps, or external portable devices, such as blood pressure monitors and glucose monitors. Data collection also benefits from the use of stationary medical instruments like X-rays and magnetic resonance machines.

Data analysis and storage: Medical personnel send the gathered data across computer networks for analysis and cloud storage. Medical professionals may easily access the data through the cloud storage, facilitating remote management and monitoring of patients' health status.

In the realm of health, a vast variety of equipment is employed, including the following: Equipment that monitors temperature, blood pressure, glucose, and other parameters is an example of external portable equipment.

2. IoMT Architecture

2.1. Selecting a Template (Sub-Heading 2.1)

The Internet of Medical Things (IoMT) is a game-changing innovation that uses Internet connectivity and smart, networked medical equipment to change healthcare. The sophisticated operation of this cutting-edge system is described by several proposed IoMT architectures, each of which includes numerous layers and components that cooperate to guarantee flawless data gathering, transmission, analysis, and decision-making. We give a thorough overview of these IoMT structures, as documented in several research articles, in this section.

The paper [3] discussed about architecture of IoMT with multiple layers and components to ensure seamless data flow, security, and interoperability. The fundamental elements of IoMT architecture included:

Sensing and Data Acquisition Layer: This layer consists of wearables, sensors, and medical devices that gather patient data in real-time, including temperature, blood pressure, heart rate, and other physiological indicators.

Data Communication Layer: The collected data is sent securely via wired or wireless networks to centralized servers or cloud platforms for storage and additional analysis.

Data Analysis and Storage Layer: The gathered data is stored in this layer, where it is processed by machine learning and advanced analytics algorithms to yield valuable insights.

The Application and UI layer: Through user-friendly interfaces, the processed data is provided to healthcare professionals, patients, or caregivers, enabling them to make educated decisions and take the necessary measures.

Security and Privacy Layer: Due to the sensitive nature of medical data, strong security measures are put in place to protect patient information from unauthorized access and online threats. These security measures include encryption and access limits.

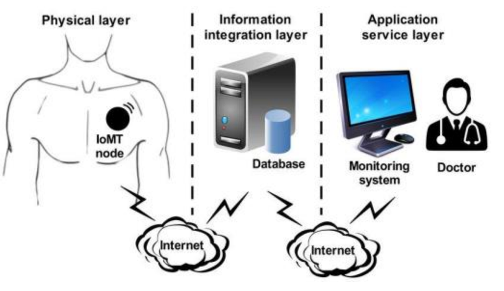


Figure 3. Architecture for the Internet of Medical Things(IoMT) [4]

In [4], a Smart healthcare system based on IoMT is discussed in detail. This system consists of a a network of numerous smart medical devices which are connected within a network through the internet. The architecture includes the following significant stages:

Data collection phase: The data collection phase, where medical data is collected from the patient's body via smart sensors linked to smart wearables or implanted devices, is the cornerstone of IoMT. Vital signs, biometric data, and other health-related information are recorded by these devices, which are a part of Body Sensor Networks (BSN) or Wireless Sensor Networks (WSN).

Data Transmission phase: The prediction and analysis phase of the architecture receives the medical data after it has been gathered and is delivered over the internet to that component. To protect sensitive patient data during transmission, this phase also includes strong data security procedures.

Analysis and decision-making phase: The acquired data is processed and interpreted utilizing powerful AI-based algorithms during the analysis and decision-making stage. This analysis aids in spotting patterns, oddities, and probable health problems, allowing for prompt intervention. Through intelligent AI-based applications on smartphones, the system may alert medical staff when a patient has a dangerous medical condition and request quick attention. IoMT equips people to take self-preventive actions based on the collected insights in less urgent situations.

Three-layer IoMT Architecture [5] proposed an IoMT architecture with three basic layers: the application layer, the perceptual layer, and the network layer.

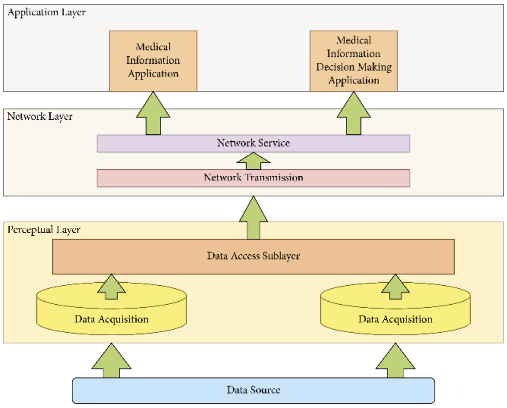


Figure 4. IoMT Architecture Overview [11]

Perceptual Layer: The perceptual layer, which is in the bottom layer, is in charge of gathering information from many sources and drawing important conclusions from the information gathered. The data access sub-layer and the data acquisition sub-layer are both parts of this layer. The data acquisition sub-layer collects data from sensors and medical devices using signal acquisition and medical perception technology, such as graphic codes, RFID, or GPRS.

Network Layer: The network layer, which is the middle layer, is responsible for platform-related services and methods of data transmission. The service layer and the network transmission layer are additional two sub-layers. Data is transmitted from the perception layer to the application layer through communication networks such as mobile networks, wireless sensor networks, and the internet by the network transmission sub-layer. On the other side, the service layer leverages open interface services to make it easier to integrate different networks, information description formats, and data warehouses.

Application Layer: The information obtained from the network layer is used by the application layer, which is the uppermost layer, to maintain medical data and enable different medical applications. The medical information decision-making application layer and the medical information application layer are two sub-layers.

The medical information application layer is home to a variety of medical tools and supplies used to retain patient data, including inpatient and outpatient records. The analysis of various types of information, such as patient data, disease data, drug data, diagnosis reports, and treatment plans, is the primary emphasis of the medical information decision-making application layer.

IoMT Architecture with Four Tiers [6] proposed four-tier architecture as discussed below:

WBSN Tier: The first tier, known as the Wireless Body Sensor Network (WBSN) tier, includes bodily-connected sensors including Electrocardiography (ECG) sensors. These sensors use wireless 802.15.6 standard communication to send the data they collect to the coordinating node.

Interface for Smart/Wireless Technology Tier: Smart devices are used for data inspection and analysis in the second tier, which is the tier that interfaces wireless and smart technologies. The data is then transmitted via wireless communication technologies or smart devices to tier 3.

Infrastructure Internet Tier: A variety of communication protocols are offered by the third tier, also known as the infrastructure internet tier, allowing effective data transport from tier 2 to tier 4.

Care Services Tier: The received data is forwarded to an intelligent server (IS) on the fourth tier, which is referred to as the care services tier. The data is stored, processed, and analysed by this server, enabling the delivery of smart medical services.

An end-to-end mHealth system design was proposed in [7] that links IoT smart sensors directly with the smart healthcare system (SHS). There are three main layers in this architecture:

Data Collection Layer: IoT devices with smart sensors that can sense and gather medical characteristics make up the bottom layer, also known as the data gathering layer. These sensors continuously collect patient-related health data.

Data Storage Layer: Medical data is kept on large-scale, high-speed storage racks by the middle layer, which is known as the data storage layer. The preservation of patient records and the facilitation of future analysis depend heavily on data storage.

A layer of data processing: The data processing layer, which is at the top of the stack, includes numerous methods for evaluating the sensor data gathered. These methods make it possible to extract useful insights from the raw data, giving medical practitioners important knowledge for diagnosis and treatment.

The IoMT architectures that are discussed in this section demonstrate the sophistication and complexity of this game-changing technology. IoMT has the potential to revolutionize healthcare delivery, remote patient monitoring, and individualized medical services through connected smart medical equipment and cognitive data analysis. These designs' meticulous planning and integration of many layers enable secure and effective operation, which eventually results in better patient outcomes and improved healthcare services. The data processing layer, which is at the top of the stack, includes numerous methods for evaluating the sensor data gathered. These methods make it possible to extract useful insights from the raw data, giving medical practitioners important knowledge for diagnosis and treatment. The adoption of IoMT architectures may have positive effects on the development of smart healthcare systems by providing both patients and healthcare professionals with priceless data-driven insights.

3. IoMT in healthcare

Patient care, illness management, and medical diagnostics have all been significantly impacted by IoMT, which has brought about a new era of healthcare applications. IoMT has transformed the collection, diagnosis, and monitoring of medical data through the development of reasonably priced and user-friendly wearable sensors, portable technology, and medical devices. The newest IoMT-based applications for the healthcare industry are examined in this section.

ECG Monitoring [8]: Through electrocardiogram (ECG) monitoring, Internet of Things technology has proven beneficial in the early detection of cardiac issues. IoT-based ECG monitoring systems have been developed by researchers using wireless data capture and real-time cardiac anomaly detection techniques. Additionally, low-power, wearable ECG monitoring systems that are built into clothing are also designed that enabled Bluetooth data transmission to users.

Glucose Level Monitoring: IoT innovations have revolutionized how diabetic patients' blood glucose levels are monitored. Real-time monitoring is provided via non-invasive glucometers with wearable sensors connected to healthcare providers via IPv6 networking. Additionally, optical sensors like near-infrared photodiodes and infrared LEDs have been successfully used to assess glucose levels.

Temperature Monitoring: IoT-based wearables that track body temperature are essential for diagnosing illnesses and providing patients with care. Accurate detection of core body temperature is now possible because of the development of wearable, 3D-printed devices worn behind the ear. Furthermore, real-time monitoring and safe data storage are made possible through the incorporation of cloud computing.

Blood Pressure Monitoring: Cuffless wearable devices that can measure both systolic and diastolic blood pressure are now possible because of IoT technology. Long-term real-time blood pressure monitoring is made possible by the combination of cloud and fog computing, with the added advantage of data archiving for future use. Blood pressure readings have also been made using ECG and photoplethysmogram (PPG) signals.

Oxygen Saturation Monitoring: The non-invasive monitoring of oxygen saturation has been transformed by IoT-based pulse oximeters. The negative impacts of a single LED can be reduced by using wearable technology with multispectral sensors. Through cloud connectivity, real-time monitoring and medical intervention decisions based on collected data become possible.

Asthma Monitoring: Internet of Things (IoT) devices for people with asthma includes intelligent sensors that precisely record breathing rates. Additionally, IoT devices using machine learning algorithms can identify patient stress levels via heart rate analysis, which is crucial information for patient treatment. Asthma monitoring systems built on the Internet of Things can also assess environmental factors and provide patients with advice that is specifically tailored to their needs.

Mood Monitoring: Convolutional Neural Networks (CNNs) used in IoT-based mood-tracking systems make it possible to classify emotional states, which is essential for the analysis of mental health. Real-time mood monitoring utilizing interactive apps, like "Meezaj," has also been developed, encouraging increased self-awareness of emotional well-being.

Medication Management: IoT-based medication management systems provide essential reminders to patients regarding their medication schedules, thus enhancing adherence. Some systems even monitor storage conditions for medications to ensure their optimal effectiveness.

Wheelchair Management: IoT offers real-time obstacle avoidance and navigation solutions, empowering patients with limited mobility through seamless interaction with wheelchairs. Wearable sensors and cloud computing enable caregivers to monitor patients remotely, assuring their safety and well-being.

Rehabilitation System: The rehabilitation process for several illnesses, including stroke and sports injuries, has been transformed by IoT technologies. Smart wearables allow for a thorough analysis of patient movements and provide individualized corrective actions.

Additional Notable Applications: Beyond the aforementioned domains, IoMT applications exist. For cancer therapy, lung cancer detection, surgical training, skin lesion detection, and other purposes, IoT-based frameworks have been developed. Additionally, photoplethysmography (PPG) sensors and LEDs have been used to monitor haemoglobin levels in the blood, offering up new opportunities for individualized treatment.

4. Emerging technologies in IoMT

This section covers a variety of cutting-edge technologies and how they fit into the overall IoMT ecosystem. [3]

Blockchain technology: Blockchain is a distributed ledger that keeps track of network computer node transactions. Blockchain provides answers to security concerns in the healthcare sector in the context of the IoT. Blockchain promotes data integrity and trust by enabling an open and tamper-proof data exchange among organizations. It makes it possible for smart contracts to be secure and self-executing without the need for a centralized authority, transforming healthcare applications.

Physically Unclonable Function (PUF) Devices: PUF devices create distinct fingerprints for weak points on the Internet of Things ecosystem. The production of secret keys to secure IoMT devices and data uses these fingerprints, which result from variances in device manufacture. PUF devices considerably improve device authentication, which increases IoMT security.

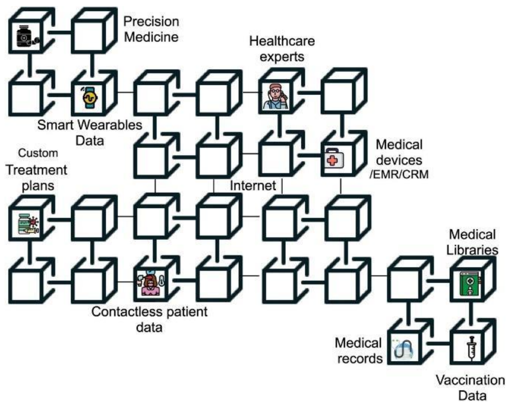


Figure 5. Use of Blockchain in IoMTs [9]

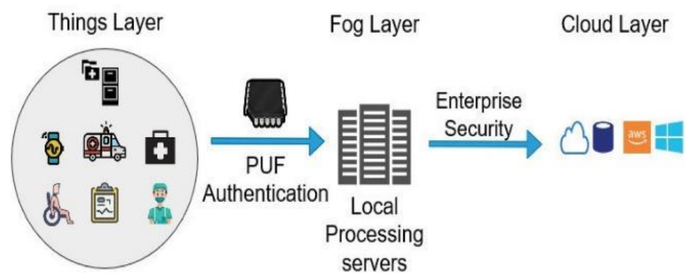
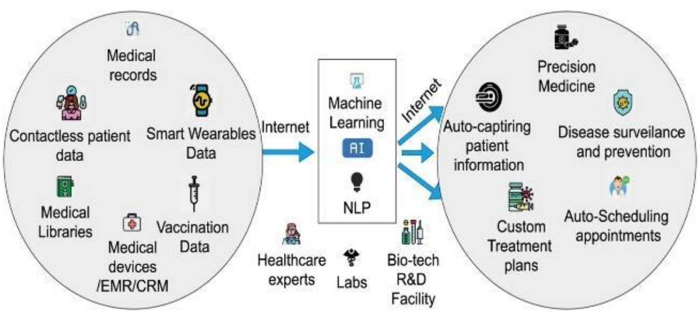


Figure 6. PUF Device Enabled IoMTs [3]

Artificial Intelligence (AI) in IoMT: Precision medicine is one of the IoMT applications where AI is especially important. Real-time analysis of past and present patient data is made possible by machine learning (ML) and natural language processing (NLP), enabling individualized treatment plans and accurate diagnosis. Patient data, appointment scheduling, treatment planning, and surgical procedures are efficiently managed using AI-based classifiers. From unstructured data points like lab results and medical notes, NLP retrieves important information.



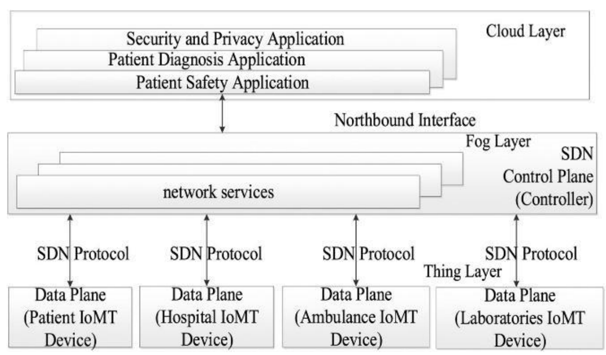


Figure 7. AI, ML and NLP Enabled IoMTs [3]

Figure 8. SDN Enabled IoMTs [3]

Software-Defined Networking (SDN) in IoMT: By facilitating effective communication between the data plane and control plane, SDN improves IoMT connectivity. Data from the data plane can be gathered and processed by external servers, including cloud-based e-healthcare apps, by employing common SDN protocols like OpenFlow and OF-CONFIG. A more developed and interconnected IoMT ecosystem is made possible by this smooth interaction with SDN.

These new technologies have great promise for revolutionizing healthcare delivery, fostering patient-centricity, and advancing medical research when integrated into the IoMT ecosystem. As we learn more about these cutting-edge technologies, their seamless integration with IoMT paves the path for a future of secure and technologically advanced healthcare.

5. Challenges in healthcare domain

Numerous issues that the healthcare sector faces necessitate ongoing focus and creative solutions. These problems affect many facets of providing healthcare, including patient care, technological integration, legal compliance, long-term financial viability, and ethical considerations. To provide everyone with high-quality and accessible treatment, healthcare professionals, politicians, and organizations must traverse a complicated terrain that includes the growing burden of chronic diseases, healthcare inequities, and the difficulties of data security and interoperability. To overcome these obstacles, coordinated efforts, technological improvements, and a dedication to patient-centric solutions are needed that results in a healthier and resilient future healthcare system. The following are some of the challenges that need to be addressed in the research works:

Data Security: The use of IoMT devices in healthcare creates serious problems with data security. These devices enhance the danger of data breaches and cyber-attacks since they capture and send sensitive patient data. Legacy medical devices without inherent security protections and connected devices that cannot be patched present unique security risks. By integrating robust cyber security plans, behavioural monitoring technology, and proactive threat mitigation, hospitals must discover ways to strengthen and maintain patient safety.

Maintaining Connectivity: To ensure uninterrupted communication and data transmission for clinicians, patients, and staff in the healthcare industry, 100 percentage connectivity is essential. The high stakes in healthcare organizations, however, necessitate a dependable network infrastructure and continuous communication. To ensure continuous connectivity, initial connection failures, limited network capacity, and physical barriers obstructing wireless signals must be handled.

Reducing Human Error: Healthcare IT expenditures and workforces may not be expanding at the same rate as hospital surroundings, which are complicated and dependent on technology. Due to the lack of resources, there is a higher chance of human mistakes, which could compromise patient safety and the standard of treatment. To lower the margin of human error and improve patient care, health IT teams are challenged to automate networks while streamlining processes and systems.

Data interoperability: For useful insights and better patient outcomes, the enormous volume of data generated by IoMT medical devices must be efficiently gathered, shared, and evaluated. However, due to many systems operating in isolation and with ineffective communication, interoperability problems frequently occur in the healthcare industry. Healthcare firms must address these issues to fully utilize IoMT data.

Regulatory Compliance: Adhering to strict regulatory requirements and gaining required license approvals are crucial for integrating IoMT devices into the healthcare sector. IoMT service providers and manufacturers have a substantial hurdle as a result of the time-consuming and expensive process of obtaining FDA certification and adhering to other requirements. The price of infrastructure: Even if IoT claims to lower healthcare costs in the long run, it might be expensive to establish the requisite IT infrastructure at first. To ensure the long-term adoption of IoMT solutions, high infrastructure expenses that must be carefully handled include those associated with hardware expenditures, cloud computing, dedicated IoMT infrastructure, and consumer-facing applications.

Standardization issues: The medical device sector has a large number of vendors and manufacturers, making standardization a difficult task. Lack of standardization can make it difficult for devices to communicate with one another and lessen the effectiveness of IoMT deployments as a whole. For seamless integration and communication between multiple IoMT devices, standards issues must be resolved.

Privacy and Ethical Problems: Using IoMT devices to collect and transmit sensitive patient data creates privacy and ethical problems. To secure patient privacy and earn their trust in implementing IoT-based healthcare solutions, healthcare firms must implement stringent data privacy policies and uphold ethical standards.

Device Mobility: To assure continuous data collection and connectivity, IoMT devices must be mobile and versatile. Physical barriers and restricted network bandwidth may provide problems for large devices, which could affect data transfer and device performance. The implementation of IoMT depends on optimizing device mobility and connectivity.

Adoption and Acceptance: To integrate IoMT solutions into healthcare operations, both patients and healthcare professionals must embrace and support them. To promote wider adoption and overcome any reluctance to change, healthcare professionals must show how IoMT improves patient care, safety, and efficiency.

To fully achieve the potential benefits of IoMT and improve healthcare delivery, it will be necessary to solve these difficulties as the healthcare industry continues to adopt IoT technology.

6. Discussion

An innovative technological paradigm with the power to completely change the healthcare sector is the Internet of Medical Things (IoMT). This study examined the role of IoMT in the healthcare industry, as well as its uses, architecture, and new technologies. IoMT offers real-time data gathering, processing, and networking by utilizing medical devices, sensors, and the Internet of Things (IoT), which leads to better patient care, better diagnostics, and more effective healthcare systems.

The discussion showed that IoMT offers a variety of uses that have the potential to revolutionize different facets of healthcare delivery. IoMT provides answers to enduring healthcare concerns, ranging from remote patient monitoring and telemedicine to smart healthcare facilities and wearable health gadgets. It makes it possible to provide individualized and remote healthcare, diagnose diseases early, and administer wellness programs proactively, all of which can improve patient outcomes and boost operational effectiveness in healthcare facilities. The article also included several proposed IoMT architectures, demonstrating the sophistication and complexity of this technology. To provide secure data transfer, interoperability, and numerous layers of functionality, these systems use many different parts and layers. Each design, from three-tier IoMT structures to smart healthcare systems, intends to promote secure data collection, transmission, analysis, and decision-making, which will ultimately result in better healthcare services and patient-centred care.

The potential of IoMT in healthcare is further increased by the incorporation of cutting-edge technologies like blockchain, Physically Unclonable Function (PUF) devices, Artificial Intelligence (AI), and Software-Defined Networking (SDN). These innovations strengthen and secure the IoMT by addressing difficulties with data security, device authentication, data analysis, and network connectivity. But along with all its benefits, IoMT also has a few drawbacks that must be overcome if it is to be successfully implemented. Some of the main obstacles to IoMT implementation are data security, connectivity, lowering human error, data interoperability, regulatory compliance, infrastructure costs, standardization, privacy and ethical concerns, device mobility, adoption, and acceptability. By utilizing connected smart medical equipment and cutting-edge data analysis, the Internet of Medical Things has the potential to transform healthcare delivery and enhance patient outcomes. Applications range from remote patient monitoring to tailored treatment regimens, and developing technologies hold out the prospect of a secure, cutting-edge healthcare system in the future.

7. Conclusion

The Internet of Medical Things has the potential to completely transform the healthcare industry by opening previously unheard-of possibilities for individualized and effective patient care. This article discussed about the role of IoT in medical domain with different architectures, healthcare applications, technologies, and challenges. IoMT's many applications, from remote patient monitoring to intelligent medical facilities, provide game-changing answers to persistent healthcare problems. Adoption of IoMT, nevertheless, also presents certain special difficulties, like assuring data privacy, regulatory compliance, and interoperability. The purpose of this paper is to promote future investigation and innovation in this quickly developing sector by shedding light on the potential advantages and complexity of IoMT.

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