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Internet of Medical Things: Architecture, Trends, Challenges, and the Evolution Towards IoMT 5.0

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Abstract: The Internet of Medical Things (IoMT) is rapidly reshaping modern healthcare by seamlessly connecting smart medical devices, patients, and care providers through intelligent networks. This paper explores the layered architecture of IoMT, highlighting the roles of sensing devices, secure data transmission, edge and cloud computing, and AI-driven analytics in delivering proactive and personalized medical care. Emerging trends such as remote patient monitoring, smart hospitals, ingestible sensors, and Augmented Reality (AR)/Virtual Reality (VR) applications in IoMT are discussed alongside critical security, privacy, and regulatory challenges. The study further examines innovative use cases and global initiatives that demonstrate the transformative potential of IoMT across diverse healthcare settings. Looking forward, we introduce the vision of IoMT 5.0 through patient-centric design and current evolving technologies such as digital twins, sustainable technologies, decentralized systems, and collaborative robotics which can drive the future of intelligent, resilient, and ethically responsible healthcare ecosystems.

Keywords: Internet of Medical Things (IoMT), smart healthcare, IoMT architecture, remote patient monitoring, smart hospitals, secure health communication, IoMT 5.0, medical cybersecurity wearable sensors, Augmented Reality (AR)/Virtual Reality (VR) in medicine

1. Introduction

The Internet of Medical Things (IoMT) refers to the integration of medical devices, healthcare software, and clinical systems through internet connectivity to support smarter, more responsive healthcare. By enabling these devices to collect, transmit, and analyze health data in real time, IoMT facilitates improved patient outcomes, enhanced workflow efficiency, and reduced operational costs. As a healthcare-focused branch of the broader Internet of Things (IoT), IoMT leverages technologies such as smart sensors, wearable monitors, implantable devices, and hospital-based equipment, all interconnected via cloud computing and Artificial Intelligence (AI). This incorporation allows for continuous health monitoring, early diagnosis, and automated care management. IoMT is transforming traditional care delivery into a more proactive and accessible model through its support for real-time data sharing, remote medical services, and intelligent decision-making [1–3]. IoMT architecture is typically structured into multiple layers, each responsible for specific functions including data acquisition, secure transmission, intelligent processing and regulatory compliance. The general framework is presented in Figure 1; this framework is divided into six layers based on the roles and responsibilities at that particular layer.

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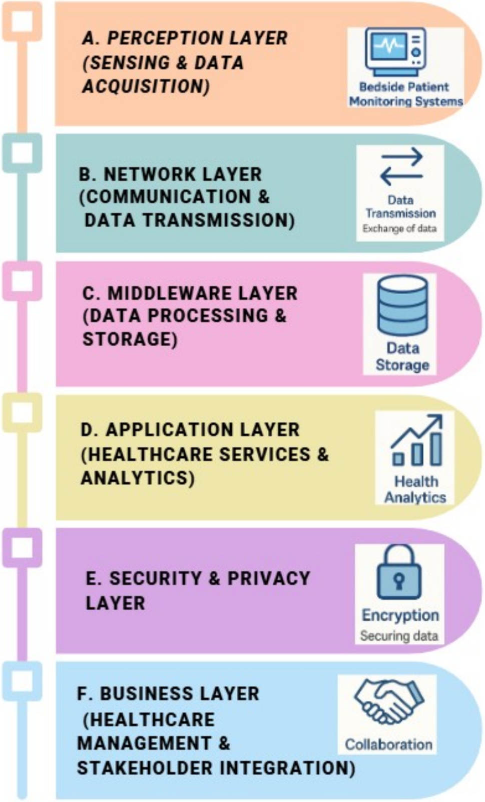
A. PERCEPTION LAYER (SENSING & DATA ACQUISITION)
Bedside Patient Monitoring Systems
B. NETWORK LAYER (COMMUNICATION & DATA TRANSMISSION)
Data Transmission Exchange of data
C. MIDDLEWARE LAYER (DATA PROCESSING & STORAGE)
Data Storage
D. APPLICATION LAYER (HEALTHCARE SERVICES & ANALYTICS)
Health Analytics
E. SECURITY & PRIVACY LAYER
Encryption Securing data
F. BUSINESS LAYER (HEALTHCARE MANAGEMENT & STAKEHOLDER INTEGRATION)
Collaboration

Figure 1. General framework of IoMT

1.1 *Perception layer (sensing & data acquisition)*

The perception Layer is a significant component of IoMT which works with the acquisition of real-time patient health information from different medical devices and sensors. These include wearable devices like smartwatches and fitness trackers, implantable medical devices like pacemakers and glucose monitors, and equipment based within the hospital, like smart thermometers and infusion pumps. Different sophisticated sensing technologies such as biometric sensors, Radio Frequency Identification (RFID), and Near Field Communication (NFC) to detect vital health parameters such as heart rate, blood pressure, oxygen saturation, and body temperature are utilized to collect the patient health information. The main goal of this layer is to provide accurate and continuous monitoring of health in early detection possible medical conditions [4, 5].

1.2 *Network layer (communication & data transmission)*

After the health information is gathered, the Network Layer ensures the secure and efficient transmission of this information to cloud servers or local processing units. The layer consists of routers, gateways, and communication protocols through which uninterrupted connectivity between medical devices and backend healthcare systems is made possible. Wireless communication technologies like Wi-Fi, Bluetooth, Zigbee, 5G, and LPWAN assist in transmitting data with negligible delay. Moreover, health-focused interoperability protocols such as Health Level Seven (HL7) and Fast Healthcare Interoperability Resources (FHIR) standardize data sharing to maintain compatibility across multiple medical platforms. This layer ensures solid, low-latency communication– especially critical in emergency health situations [4, 6].

1.3 *Middleware layer (data processing & storage)*

The Middleware Layer serves as an intermediary between raw data gathering and detailed analysis. It sorts, screens, and temporarily stores medical information prior to forwarding it for additional assessment. To be more efficient, edge computing is generally used at this point, allowing real-time data processing near the source and minimizing network traffic. Also, fog computing offers mid-level processing between edge devices and cloud infrastructure. For massive data management and analysis, cloud platforms such as Amazon Web Services (AWS), Microsoft Azure, and Google Cloud are used. This layer also incorporates Artificial Intelligence (AI) and machine learning algorithms to identify anomalies, normalize data, and optimize storage needs. By making sure that only pertinent and filtered data is passed for analysis, the Middleware Layer improves system performance and decision-making abilities [7].

1.4 *Application layer (healthcare services & analytics)*

The Application Layer converts processed information into actionable intelligence for healthcare workers and patients. It includes Remote Patient Monitoring (RPM) solutions, Electronic Health Record (EHR) systems, artificial intelligence-enabled diagnostic tools, and mobile health (mHealth) applications. Healthcare workers are able to monitor patient health remotely, receive real-time notifications for life-threatening situations, and make data - driven treatment decisions. Analytics with AI also help forecast possible health threats, including cardiac arrests or diabetic foot complications, by processing historical and current health information. Patients also gain from this layer, as they are able to view their health statistics through smartphone applications, allowing improved control of chronic illnesses. By closing the gap between raw data and real-world healthcare application, this layer enhances telemedicine, prevention, and individualized treatment methodology [8].

1.5 *Security & privacy layer*

The medical information is of sensitive nature and hence the Security & Privacy Layer is an essential part of IoMT architecture. It protects patient data as confidential, tamper-proof, and in accordance with healthcare compliance laws. Secure encryption methods like Advanced Encryption Standard (AES) and Rivest-Shamir-Adleman (RSA) protect data storage and transmission. Access control measures like biometric authentication, two-Factor Authentication (2FA), and OAuth prevent unauthorized entry. Blockchain technology is widely deployed to develop secure, robust and transparent health records. Moreover, cybersecurity solutions such as Intrusion Detection Systems (IDS) and firewalls keep data breaches away. Compliance with regulations such as the Health Insurance Portability and Accountability Act (HIPAA), General Data Protection Regulation (GDPR), and Food and Drug Administration (FDA) guidelines are strictly followed in order to keep data intact and patients' confidence intact [3, 7].

1.6 *Business layer (healthcare management & stakeholder integration)*

The Business Layer targets the integration of IoMT solutions into the overall healthcare environment to allow hospitals, insurance companies, and policymakers to effectively utilize medical data. It interfaces with Hospital Management Systems (HMS), insurance claim handling systems, and Decision Support Systems (DSS) to automate administrative functions and maximize healthcare resources. Hospitals are able to improve patient care efficiency, reduce operational expenses, and enhance resource allocation. Insurance companies use IoMT - collected data for fraud prevention and customized health insurance plans, whereas government health authorities use aggregated data for public health surveillance and policy-making. This layer makes sure that IoMT not only enhances medical outcomes but also increases the economic and administrative effectiveness of healthcare systems [9, 10].

Together, these interconnected layers form a robust IoMT architecture that supports the IoMT framework data from acquisition of medical data and secure transmission to intelligent analysis while ensuring privacy, compliance, and business integration. This layered framework not only enhances patient care and operational efficiency but also empowers stakeholders across the healthcare spectrum to make informed, data-driven decisions. Understanding the role and interplay of each layer provides essential context for exploring the specific devices, technologies, and challenges discussed in the following sections. By integrating these layers, the IoMT architecture establishes a comprehensive digital health ecosystem that transforms healthcare delivery through real-time monitoring, predictive analytics, and seamless end-to-end connectivity. The remainder of this paper is organized as follows: Section 2 reviews related work, Section 3 discusses various IoMT devices, and Section 4 presents technology-enabled healthcare systems. Section 5 provides case studies, followed by security and privacy considerations in Section 6. Future directions towards IoMT 5.0 are explored in Section 7, and concluding remarks are offered in Section 8.

2. Related work

An Internet of Things (IoT) framework in combination with machine learning methods for the early diagnosis of heart disease is proposed in [1]. It describes how physiological data is captured in real time by wearable devices, which are then processed through ML algorithms to detect early manifestations of cardiac diseases. The proposed framework is meant to facilitate timely clinical decisions and enhance patient outcomes by monitoring patients continuously. Khan et al. propose an IoT-based system for heart disease prediction with the help of a Multi-Domain Convolutional Neural Network (MDCNN) classifier. The system analyses data from IoT-based sensors and detects cardiac abnormalities with high precision. Their solution focuses on real-time processing, enhanced diagnostic accuracy, and efficient remote patient monitoring to achieve optimal heart disease care [11].

The application of health sensors, smart home technology, and the Internet of Medical Things (IoMT) to enhance diabetic patient care for lower extremity complications are investigated in [2]. The enabling of continuous monitoring, early identification, and prompt interventions through networked devices is highlighted. Integrating such technology into patient management, holds immense promise for decreased hospitalization and improved patient outcomes in diabetic foot health. The idea of a “Smart Ambulance” that incorporates Internet of Things (IoT) and cloud technology to improve emergency medical care is introduced in [3]. This system is a combination of fingerprint sensors for safe patient identification and medical sensors that track vital signs such as heart rate, blood pressure, and oxygen saturation in real time during transport. This method is designed to enhance patient care by offering timely information to healthcare professionals, enabling immediate interventions.

AMBtalk, a novel cardiovascular Internet of Things (IoT) system specifically for ambulances is introduced in [12]. The device facilitates real-time cardiovascular monitoring and wireless transmission of critical data for enhanced emergency response and patient treatment in transit. It facilitates smooth communication of data from ambulances to hospitals so that medical staff are adequately prepared on arrival. This study emphasizes the role of IoT in improving pre-hospital care and minimizing response time in acute cardiovascular emergencies. A real-time Delphi study to investigate future directions in smart hospital evolution is carried in [13]. The study focuses on how the evolving technologies of AI, IoT, and robots will reshape hospital operations to improve patient care, workflow, and decision-making. It puts forward critical areas of personalized medicine, integration of data, and remote monitoring of patients. The study offers strategic guidance to healthcare stakeholders looking to transform to technological changes in contemporary hospital settings.

The evolution of Philips from a conventional electronics company to a dominant force in healthcare technology is studied in [14]. The article describes how the company tactically realigned its focus toward medical devices, digital diagnostics, and health monitoring systems. Philips’ incorporation of innovation, research, and worldwide collaboration to overcome contemporary healthcare challenges is highlighted by their research. This transformation shows how technology-led firms can evolve to suit the needs of the healthcare industry. Ahmad et al. [15] offer an in-depth analysis of how emerging technologies are used to improve remote healthcare and assisted living technology. The research delves into how technologies like IoT, AI, wearable sensors, and 5G networks are used for real-time monitoring of health, enhanced patient care, and greater autonomy for older and chronically ill people. The authors also mention security issues, interoperability, and data privacy concerns involved in implementing these technologies. Their research charts directions for developing intelligent, networked health systems that enable ongoing, patient- focused care.

A deep learning-based model to identify cyber threats in the Internet of Medical Things (IoMT) system is proposed in [16], discusses how neural network models can detect malicious patterns in IoMT traffic data to improve digital health security. The need to integrate intelligent models to counter growing cyber vulnerabilities in healthcare systems is been stressed. Different findings reveal enhanced detection precision and fewer false alarms, supporting the application of deep learning in the protection of medical IoT infrastructures. The use of artificial intelligence for enhancing the security of the Internet of Medical Things (IoMT) is presented in [17]. The detailed evaluation of AI-driven threat detection techniques, vulnerability management, and the protection of sensitive medical information is carried out. More emphasis is given on how AI integration with IoMT improves real-time decision-making, threat detection mechanisms, and facilitates adaptive security policies on healthcare networks. This thorough analysis proves the indispensable role of AI in protecting next-generation medical technology.

The above literature demonstrates significant advancements in IoMT applications, starting from early disease diagnosis and emergency response systems to AI-driven security frameworks and smart healthcare infrastructure. The next section provides an insight about various IoMT devices that form the backbone of this evolving healthcare ecosystem by highlighting their functionalities and contributions to real-time health monitoring.

3. Different IoMT devices

In recent years, various Internet of Medical Things (IoMT) devices have emerged as a transformative force in healthcare, merging real-time data collection with advanced connectivity to support proactive medical interventions. These compact and sensor-driven technologies are divided into two categories namely wearable devices and implantable devices as shown in Figure 2. These devices ranging from smartwatches and fitness trackers to implantable monitors, enable continuous monitoring of vital signs, physical activity, and even chronic disease indicators. By bridging the gap between patients and providers, these IoMT devices not only enhance personalized care but also contribute to more efficient, data-informed healthcare systems.

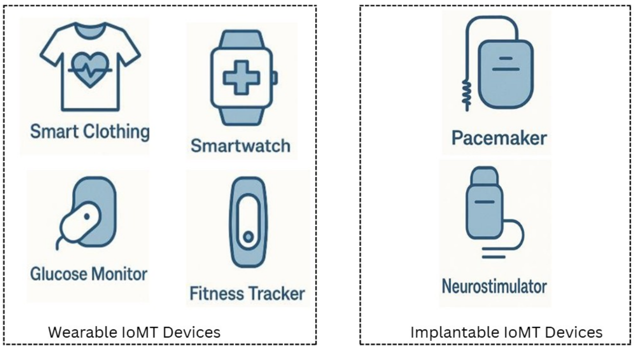

Figure 2. Different IoMT devices

3.1 *Wearable IoMT devices*

Wearable IoMT devices are sensor-based, non-invasive devices that are meant to continuously monitor several physiological parameters in real time. Some of the wearable IoMT devices are shown in Figure 2. They consist of smartwatches (e.g., Apple Watch, Fitbit), ECG patches, pulse oximeters, and clothing with biosensors. They track important health parameters like heart rate, oxygen saturation (SpO_2), body temperature, physical activity, and sleep patterns through optical, thermal, and motion sensors. Certain sophisticated wearables, for instance, Continuous Glucose Monitors (CGMs), employ subdermal electrodes to monitor blood glucose levels without finger pricking. In the same vein, neurological wearables, including EEG headbands, assist in monitoring brain activity for applications such as epilepsy and sleep disorders.

These gadgets employ embedded systems or Wi-Fi to transfer data onto smartphones or gateway devices that relay the information to cloud-based platforms for secondary analysis. Artificial Intelligence (AI) software processes this information to detect anomalies, for example, atrial fibrillation or hypoglycemia, and send alerts to patients and health providers. For example, the Apple Watch, which was Food and Drug Administration (FDA) approved for detecting arrhythmia, can alert users to unusual heart rhythms. Furthermore, these wearables are made to connect with Electronic Health Records (EHRs) using standardized protocols such as HL7/FHIR, providing seamless data sharing with hospitals and healthcare systems.

Wearable IoMT devices can also prioritize power efficiency to support extended and uninterrupted use, in case of low-power sensors for optimized battery management. User comfort and ease of operation are critical factors, as wearables sensors must ensure towards consistent patient monitoring. Along with their advantages, wearable devices face some challenges such as sensor accuracy variations, connectivity disruptions and the need for standardized data formats to ensure reliable and interoperable healthcare integration [18].

3.2 *Implantable IoMT*

Implantable IoMT devices refer to surgically implanted medical devices that offer ongoing monitoring and care for chronic diseases, some of these devices are shown in Figure 2. Cardiac implants like pacemakers and implantable defibrillators manage heart rhythm and avert cardiac arrhythmia occurrences. Insulin pumps manage diabetes by continuously adjusting insulin infusion according to real-time blood glucose. Neurological implants, such as neurostimulators and Responsive Neurostimulation Systems (RNS), assist in the management of diseases like epilepsy, Parkinson’s disease, and chronic pain. The devices send important health information to healthcare providers, which allows them to intervene promptly. Made for continuous use, they enhance patient outcomes and connect to smartphone apps for remote monitoring and tuning [19].

3.3 *Stationary medical IoMT*

Stationary medical IoMT devices comprise sophisticated diagnostic, critical care, and hospital management systems that optimize healthcare efficiency. IoT-enabled MRI and CT scanners leverage AI for image reconstruction and predictive maintenance, while intelligent ultrasound systems facilitate wireless imaging and AI-driven diagnostics. Networked ventilators dynamically adjust oxygen levels and integrate with ICU dashboards for centralized monitoring. Intelligent infusion pumps prevent medication errors through barcode- based verification. Smart hospital beds track patient comfort and integrate with nurse call systems for enhanced surgical workflow. These innovations improve patient care, minimize errors, and streamline hospital operations.

3.4 *Ingestible IoMT*

Ingestible IoMT technologies are new generation digital health technology products that monitor real-time inside-body conditions in the form of pill-sized electronic technology. Some ingestible products have microsensors, cameras, or RFID tags to detect medication compliance, do diagnostic imaging, and assess physiological parameters. Several of these don’t rely on conventional batteries as they take energy from a chemical reaction induced by stomach acids, and radio-wave signals forward to external receiver systems. Applications range from medication compliance monitoring, capsule endoscopy for gastrointestinal imaging, to real-time monitoring of body temperature and pH. AI- based analysis provides enhanced diagnostics through detection of conditions such as ulcers, tumors, and inflammation. To ensure safety, these devices comply with strict FDA/CE regulations, employ encrypted data transmission, and exit the body naturally within 24-48 hours.

3.5 *IoMT analytics and intelligence*

The expansion of IoMT devices has led to vast streams of physiological and clinical data, but their real value lies in the ability to convert raw measurements into actionable intelligence. IoMT analytics serves as a critical bridge, enabling timely diagnosis, prognosis, and therapy optimization. These systems must handle diverse, continuous, and sensitive data, ranging from high-frequency ECG signals to periodic glucose readings, each requiring tailored analytical methods. Advanced machine learning and deep learning approaches including convolutional and recurrent neural networks play a key role in detecting anomalies, forecasting health risks, and supporting precision care [20].

The analytical workflow in IoMT typically involves four stages: data acquisition and secure transmission, signal pre-processing for reliability, model-based analysis for pattern recognition, and decision support through interpretable outputs such as alerts and dashboards. Cloud-based infrastructures such as AWS, Google Cloud, and Microsoft Azure provide scalable platforms that integrate storage, analytics, and AI services, while edge intelligence frameworks like TensorFlow Lite and TinyML enable low-latency, on-device processing. Together, these platforms and techniques highlight the shift from passive data collection to intelligent, real-time healthcare delivery [21, 22].

In summary, the diverse range of IoMT devices comprising wearable, implantable, stationary, and ingestible technologies contribute to a comprehensive digital healthcare ecosystem. Each category addresses specific medical needs by enabling continuous monitoring, accurate diagnostics, and timely interventions. The integration of AI and connectivity across these devices enhances patient care by supporting data-driven decision-making in healthcare systems. The next section explores how these various IoMT devices come together within technology-enabled healthcare frameworks to transform medical services and patient outcomes.

4. Technology-enabled healthcare ecosystem

The modern healthcare ecosystem is undergoing a profound transformation, driven by the integration of advanced technologies that enhance the delivery, accessibility, and quality of care. From electronic health records and telemedicine platforms to AI-powered diagnostics and remote patient monitoring, these digital tools are reshaping how healthcare is managed and experienced. A technology-enabled healthcare ecosystem fosters seamless communication between patients, providers, and systems, leading to more coordinated and personalized care. Various components of Technology Enabled Healthcare Ecosystem are shown in Figure 3.

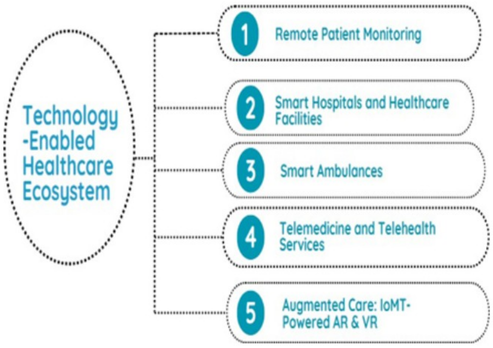
Technology -Enabled Healthcare Ecosystem
1 Remote Patient Monitoring
2 Smart Hospitals and Healthcare Facilities
3 Smart Ambulances
4 Telemedicine and Telehealth Services
5 Augmented Care: IoMT-Powered AR & VR

Figure 3. Technology enabled healthcare ecosystem

4.1 *Remote patient monitoring*

Remote Patient Monitoring (RPM) enables healthcare professionals to monitor patient health remotely with the use of digital devices. It manages chronic conditions such as diabetes and heart ailments by monitoring vital signs continuously. The technology minimizes hospital visits and allows detection of complications early on. In the COVID-19 pandemic, RPM significantly contributed to reducing in-person consultations. In spite of its advantages, issues such as data security and device compatibility persist. Along with these benefits, there are challenges related to data security, patient privacy, device interoperability, and compliance with regulations such as HIPAA and GDPR remain critical considerations for effective and safe deployment [23].

4.2 *Smart hospitals and healthcare facilities*

Smart hospitals utilize cutting-edge technologies such as IoT, AI, and automation to improve healthcare services. These facilities improve the monitoring of patients, enhance treatment planning, and streamline hospital processes. AI-based analytics aid in disease diagnosis, resource management, and avoiding medical errors. Automated processes, robotic surgery, and digitalized records improve efficiency and patient safety. Smart healthcare solutions, however, need high investment and robust cybersecurity.

4.3 *Smart ambulances*

Intelligent ambulances use sophisticated medical equipment and digital communication devices to enhance emergency response and patient care. They are fitted with real-time monitoring equipment like ECG machines, ventilators, and oxygen sensors to monitor a patient's condition during transportation. Live data transmission to hospitals enables doctors to evaluate the situation beforehand and prepare for instant treatment. GPS technology and route optimization through automation enable ambulances to travel faster to destinations, minimizing delays in emergency situations. Telemedicine capabilities allow paramedics to remotely consult specialists, enhancing decision-making for emergency treatment. Electronic health records are also integrated into smart ambulances, providing easy access to patient history for proper treatment. While they have advantages, challenges like connectivity problems, high costs of implementation, and cybersecurity threats need to be overcome. Improved infrastructure and implementing standard protocols can boost the reliability and efficiency of intelligent ambulance systems [24].

4.4 *Telemedicine and telehealth services*

Telemedicine allows virtual healthcare services via video calls, mobile apps, and remote monitoring. Telemedicine enhances access to healthcare, particularly for patients in rural areas with poor healthcare infrastructure. The method has been effective in treating different conditions, with decreased hospital congestion and expense. Telemedicine became universally accepted during the COVID-19 pandemic to maintain continuity of care. But problems such as internet connectivity, privacy issues, and regulatory frameworks must be resolved. However, challenges remain, including issues with internet connectivity, patient data privacy and the need for clear and comprehensive regulatory frameworks to support safe and equitable telehealth practices [25].

4.5 *Smart bandages*

Smart bandages are innovative wound dressings embedded with sensors that continuously monitor the healing process in real-time. These sensors track critical parameters such as temperature, pH levels, moisture, and the presence of infection-causing bacteria. The collected data is wirelessly transmitted to healthcare providers, enabling continuous remote monitoring without frequent bandage changes or hospital visits. This technology facilitates personalized wound care by allowing early detection of complications and promoting faster healing. Smart bandages are especially beneficial for managing chronic wounds, including diabetic ulcers, burns, and surgical wounds, ultimately enhancing patient outcomes while reducing overall healthcare costs.

4.6 *Biodegradable sensors*

Biodegradable sensors are flexible, implantable devices designed to monitor physiological signals such as temperature, pressure, or biochemical markers inside the body. Made from materials that safely dissolve over time, these sensors eliminate the need for surgical removal after their function is complete. They play a critical role in temporary monitoring applications, like post-surgery recovery or drug delivery tracking. By combining biocompatibility with wireless communication capabilities, biodegradable sensors provide real-time data to clinicians while minimizing patient discomfort and long-term risks associated with permanent implants.

4.7 *Augmented care: IoMT-powered AR & VR in healthcare*

Healthcare is moving into a new age where technology becomes the biggest driver of better patient care. Technologies such as Augmented Reality (AR) and Virtual Reality (VR), when coupled with the Internet of Medical Things (IoMT), provide enormous means of helping doctors and patients. From devices that monitor health metrics via wearables to visual displays that assist surgeons in real-time, these technologies are making treatments more accurate. VR is also being applied to therapy and rehab, allowing patients to recover in interactive, engaging ways. While AR is enabling patients to better comprehend complicated procedures through visual means. While there are challenges such as cost, data privacy, and system compatibility, the advantage is evident. As networks speed up and become smarter, these tools will only become more beneficial. Together, they're revolutionizing healthcare into something more responsive, connected, and effective.

Recent advancements in AR and VR technologies are expanding their role beyond the traditional application in healthcare system. Few examples include, AR-assisted surgery platforms which allow surgeons to work with 3D anatomical models onto patients in real time, improving precision and reducing operative risks. VR-based pain management and mental health therapies are gaining popularity which is helping patients manage chronic pain, anxiety, and mental disorders. Research is also exploring the use of VR simulations for medical training, providing immersive environments for students and professionals to practice complex procedures without risk. As these technologies are mature and becoming more affordable, their integration into regular medical practice promises to enhance patient outcomes, medical education, and overall healthcare efficiency [26, 27]. These innovations in technology enabled systems enhance real-time monitoring, improve treatment accuracy, optimize hospital operations and increase access to medical services.

5. Case studies related to IoMT

Case studies in the Internet of Medical Things (IoMT) provide valuable insights into how connected medical technologies are being applied to improve patient outcomes and healthcare efficiency. The continuous flow of real-time data helps to detect abnormalities earlier, significantly reducing hospital readmissions. Different case studies demonstrate how IoMT can move care beyond traditional clinical settings, offering scalable, patient-centered solutions through data connectivity and real-time monitoring. This section summarizes different case studies of IoMT that are already implemented in real time. Table 1 shows a summary of different case studies based on IoMT, highlighting the outcome of the work and its implementation scalability.

These examined case studies demonstrate how IoMT solutions are being applied in diverse healthcare settings, including emergency services, remote monitoring, cancer care and system security. Table 1 shows benefits of these studies along with the some of limitations with respect to scalability which include practical barriers, large-scale adoption and infrastructure gaps. Collectively these findings emphasize that while IoMT is already reshaping healthcare practices, its long-term impact will depend on how effectively issues of trust, security, and privacy are addressed.

Table 1. Different case studies related to Internet of Medical Things (IoMT)

Paper	Description	Outcome of Case Study	Scalability
Ayesha, A. & Komalavalli, C. (2023) [24]	Developed a fingerprint-based smart ambulance system with medical sensors to monitor real-time patient vitals.	Enabled secure patient identification and faster response through real-time data transmission to hospitals.	Moderate–Works well in urban areas with stable networks; challenges remain in rural areas due to connectivity and cost.
Seth, M. et al. (2025) [28]	Conducted a scoping review on IoMT platforms, focusing on technologies and protocols for managing emergencies with interoperability challenges.	Identified key standards and gaps, promoting improved interoperability for better emergency coordination.	High–Standards-based framework supports wide-scale adaptability and interoperability across regions.
Chandekar, P., Mehta, M., & Chandan, S. (2025) [29]	Introduced ensemble AI models for real-time anomaly detection to enhance cybersecurity in IoMT systems using the CICIoMT2024 dataset.	Improved security and resilience of smart ambulance communication systems.	High–Modular AI architecture enables easy integration across IoMT platforms.
Kim, J., et al. (2024) [30]	Evaluated a remote monitoring system with portable ECG devices connected via IoMT to monitor hikers' heart health in real time.	Among 2,000 participants, 15.9% showed abnormal ECG signals; 93.08% were advised hospital visits, enabling early cardiovascular detection and treatment.	High–Proven effective at scale; suitable for mass deployment in remote or outdoor monitoring scenarios.
A. Gottlob (2025) [31]	Explored integration of telemedicine in cancer care across five EU countries during COVID-19, highlighting regulatory changes, barriers, and facilitators.	Telemedicine uptake increased during the pandemic but declined afterward due to preference for in-person visits and policy gaps; issues remain with data privacy and infrastructure.	Moderate–Strong potential in crisis scenarios; requires policy alignment and infrastructure support for sustained large-scale use.

6. Security and privacy considerations

As the IoMT continues to expand, so do the challenges related to security and privacy. These connected devices often handle sensitive patient data, such as vital signs, medical histories, and real-time health metrics, making them valid targets for cyberattacks. Ensuring data integrity and confidentiality is critical, particularly in environments where information is transmitted wirelessly and stored across multiple platforms. Weak encryption, poor device authentication, and lack of regular software updates can expose systems to unauthorized access, data breaches, and even life-threatening disruptions. Moreover, privacy concerns arise when patient data is shared across networks without clear consent or adequate control mechanisms. In this section, some technologies are suggested that can help to incorporate security and privacy measures. Building trust in these technologies requires a strong commitment to both protecting personal health information and maintaining system resilience

6.1 *Data protection mechanisms*

Securing patient information requires a mix of encryption, secure networks, and access controls to keep unauthorized exposure from occurring. Encryption transforms medical records into coded form, which only authorized personnel can decode and view. Firewalls and intrusion detection systems assist in monitoring network activity and stopping cyberattacks on healthcare databases. Role-based access controls ensure that authorized healthcare personnel will be able to see or amend patient records to minimize the opportunity for misuse. Blockchain is used to advance the integrity of the data, which provides a secure, tamper-proof mechanism for medical records. Software patches and regular updates assure vulnerabilities are plugged and health care IT infrastructure strengthened. Cloud services with end-to-end encryption protect data storage and access and respect privacy laws. Organizations should regularly review and enhance their security controls to fend off new attacks and provide patient data assurance [7].

6.2 *Compliance with healthcare regulations*

Health care organizations in India are required to adhere to the Digital Personal Data Protection Act (DPDPA), 2023 and Information Technology Act, 2000 to maintain confidentiality of patient information. These enactments mandate hospital organizations to impose stringent data storage, access restriction, and secrecy measures. Bi-annual auditing and compliance surveillance prevent data hacking and unauthorized intrusion into confidential patient records. A failure to abide by these could result in very serious legal action and financial penalty against health providers. With developing technology, regulatory standards are always revised to accommodate new security issues that arise within the medical field [15].

Healthcare organizations must also align with international data protection frameworks such as the Health Insurance Portability and Accountability Act (HIPAA) in the United States and the General Data Protection Regulation (GDPR) in the European Union. These frameworks emphasize patient rights, data minimization, and accountability in handling sensitive health information. For IoMT systems that operate across borders, regulatory compliance requires adherence to domestic laws as well as careful consideration of international standards to ensure interoperability and legal consistency. Consequently, regulatory compliance in IoMT is not a one-time requirement but an ongoing process that must evolve with technological innovation and emerging risks [32].

6.3 *Blockchain-based medical record management*

A blockchain-driven approach to managing medical records ensures robust security through cryptographic techniques and decentralization. Once information is added, it becomes tamper-proof, preserving the integrity of patient data. Individuals maintain control over who can access their health information, enabling secure and selective sharing. This model also enhances compatibility between different healthcare systems, making data exchange more seamless and efficient [33].

The large volume of medical data generated by IoMT devices makes on-chain storage impractical, leading to concerns about scalability and network congestion. Public blockchain systems may also suffer from latency and high energy consumption, which are unsuitable for time-sensitive healthcare operations. Furthermore, the lack of standardized frameworks and varying regulatory requirements across regions complicate the integration of blockchain into existing healthcare infrastructures. These challenges underscore the need for tailored solutions that balance blockchain's security benefits with the practical demands of medical systems. Researchers are exploring hybrid approaches where blockchain is used primarily for securing transaction records and access permissions, while the actual medical data is stored off-chain in encrypted cloud systems to address various limitations. Such architectures preserve blockchain's immutability and transparency by overcoming storage and performance constraints [34, 35]. Technical mechanisms such as encryption, access controls and blockchain strengthen data protection. Regulatory compliance and governance frameworks provide the necessary oversight to maintain trust and accountability.

7. Future trends: towards IoMT 5.0

The evolution of IoMT is steadily progressing toward a new paradigm often referred to as IoMT 5.0, where the integration of advanced technologies will redefine the future of connected healthcare. This next phase envisions a more intelligent, autonomous, and human-centric ecosystem, driven by innovations such as Artificial Intelligence (AI), 5G connectivity, edge computing, and digital twins. IoMT 5.0 aims to enable real-time, predictive, and personalized healthcare experiences by enhancing device interoperability, reducing latency, and empowering devices to make on-the-spot decisions. For example, wearable devices could not only detect irregular heart rhythms but autonomously alert emergency services and initiate immediate interventions. Following are some of the technologies that may facilitate in the robust and effective IoMT 5.0.

7.1 *Human-centric IoMT: empowering patients and clinicians*

The integration of human-centric design principles into the Internet of Medical Things (IoMT) emphasizes personalized care and user empowerment. By involving patients and clinicians in the design process, IoMT solutions enhance usability and foster trust. These systems enable real-time monitoring, improve decision-making, and support shared control over medical data. Such a shift promotes active patient engagement and tailored treatment strategies. Recent studies highlight the need for ethical, inclusive design in AI- powered healthcare tools [36].

Implementing human-centric IoMT faces several practical challenges. Ensuring accessibility across different populations, including elderly patients and those in resource-limited environment, is critical for achieving equity in healthcare delivery. At the same time, balancing all users with robust data protection mechanisms remains a challenge, as greater patient control over medical data can introduce new security and interoperability demands. Overcoming these barriers require interdisciplinary collaboration between technologists, doctors, policymakers, and patients themselves, ensuring that the next generation of IoMT systems is both technologically advanced and socially inclusive.

7.2 *Sustainable and green healthcare through IoMT 5.0*

Sustainability, a cornerstone of both Industry 5.0 and IoMT 5.0, calls for energy-efficient and environmentally responsible digital health systems. In a paper published by ETH Zurich, researchers propose edge-computing-enabled IoMT architectures to reduce the energy consumption associated with cloud transmission, while Horizon Europe projects like SmartEES2 focus on biodegradable sensors and materials to reduce e-waste in wearable health devices. This shift not only supports the European Green Deal, but also aligns with circular economy principles by minimizing the ecological impact of health technology deployments [37].

7.3 *Resilient and decentralized medical ecosystems*

The COVID-19 pandemic underscored the vulnerability of centralized healthcare systems, prompting a push toward resilient, decentralized models. IoMT 5.0 integrates blockchain, edge AI, and self-healing network topologies to ensure robustness and continuity of care in adverse conditions. The EU SHAPES project (Smart and Healthy Ageing through People Engaging in Supportive Systems) demonstrated how distributed health-monitoring platforms can maintain real-time diagnostics and service delivery across aging populations during crises. These technologies ensure that resilience is embedded into the fabric of healthcare infrastructures [37].

7.4 *Digital twins in IoMT 5.0 for precision monitoring*

The concept of digital twins in IoMT 5.0 offers a transformative approach to healthcare by enabling real-time, high-fidelity simulations of patients' physiological conditions. These virtual replicas continuously sync with data from wearable devices and medical sensors, allowing clinicians to monitor health parameters with pinpoint accuracy. By simulating possible health scenarios, digital twins support early detection of anomalies and facilitate proactive intervention. This leads to more personalized care plans and improved patient outcomes. The fusion of digital twin technology with IoMT marks a significant leap toward predictive and precision medicine [38].

Beyond individual patient care, digital twins have the potential to revolutionize multiple dimensions of healthcare delivery. In medical training, they can provide realistic simulations for clinicians to practice procedures without risk to patients. In surgical planning, digital twins may allow physicians to test interventions virtually before performing them in real settings, thereby reducing complications. At a user level, aggregating anonymized digital twin data can enhance epidemiological modeling and resource allocation, supporting more resilient healthcare systems. Rehabilitation and chronic disease management can also benefit, as continuous simulations offer personalized feedback and adaptive treatment strategies that evolve with patient progress. Alog with these benefits, the implementation of digital twins in IoMT presents significant challenges. The continuous synchronization of high-resolution physiological data requires immense computational resources and robust interoperability standards across devices and platforms. Privacy concerns are amplified, as the granularity of data needed for accurate simulations could expose sensitive patient information if not properly protected. Additionally, the absence of universally accepted frameworks for validating and regulating digital twin models raise concerns regarding reliability, safety, and clinical accountability. Overcoming these barriers will be essential for digital twins to move from experimental pilots to large-scale, trusted components of IoMT 5.0 ecosystems [39, 40].

7.5 Robotics in surgery within IoMT 5.0: precision with human oversight

Surgical robotics is a critical frontier in IoMT 5.0, integrating real-time data, artificial intelligence, and remote connectivity to enhance surgical precision while preserving human oversight and empathy are key pillars of Industry 5.0. Unlike traditional robotic surgery in Industry 4.0, which prioritized automation, IoMT 5.0 introduces collaborative, context-aware robotic systems that work with surgeons, rather than replacing them. The DIH-HERO (Digital Innovation Hubs in Healthcare Robotics) project, funded by the European Commission, emphasizes developing interoperable robotic platforms that support surgeons in minimally invasive procedures, enhanced by real-time IoMT data streams from biosensors, cameras, and haptic feedback systems. Similarly, the RASimAs project (Regional Anaesthesia Simulator and Assistant) leverages robotic arms connected to IoMT-based imaging to guide anesthetists using 3D anatomical models. These systems align with Industry 5.0's principles by focusing not only on precision but also on patient safety, surgeon ergonomics, and ethical responsibility through AI explainability and transparent robotic decision-making [41].

Despite their transformative potential, the deployment of IoMT and digital twin technologies is accompanied by several unresolved challenges. Ethical concerns are particularly pressing, as continuous health data collection raises questions about informed consent, data ownership, and the possibility of algorithmic bias in AI-driven models. If not addressed, these risks can compromise patient autonomy and undermine trust in connected health systems. Technical barriers also persist, with real-time clinical applications often hindered by latency in data transmission. Although edge computing offers partial relief by processing data closer to the source, it requires additional infrastructure and increases system complexity. Financial considerations represent another obstacle, as the creation and maintenance of digital twins demand substantial investment in computational resources, data integration, and clinician training, which may not be feasible for all healthcare institutions. Finally, interoperability remains a bottleneck, since IoMT devices and platforms frequently rely on disparate standards and communication protocols, limiting seamless integration and scalability. Addressing these ethical, technical, financial, and compatibility issues will be essential for moving IoMT and digital twin systems from experimental pilots to sustainable, real-world healthcare solutions.

IoMT 5.0 represents a decisive shift toward healthcare systems that are not only intelligent and interconnected but also human-centric, sustainable, and ethically grounded. Emerging technologies such as AI-driven analytics, digital twins, and collaborative surgical robotics are expected to transform clinical practice by enabling predictive, personalized, and minimally invasive care. At the same time, the integration of eco-friendly design principles and interoperable standards highlights the growing commitment to long-term sustainability and inclusivity.

8. Conclusion

IoMT is transforming healthcare by integrating smart devices, real-time monitoring, and AI-driven analytics for better patient outcomes. Advanced tools like digital twins, remote monitoring, and AI-assisted diagnostics enhance disease management and personalized treatments. Security and regulatory challenges require robust data protection mechanisms to ensure patient privacy and compliance. This paper presents, various key components of IoMT technology, starting from its framework and devices to its technologies, case studies and security concerns. Overall this paper can help researcher who are planning to develop IoMT system to look in various aspects of that system and com up with the design. With continuous advancements, IoMT is set to revolutionize medical care, making it more efficient, predictive, and accessible.

As the IoMT technology look promising, the widespread adoption of IoMT still faces practical and ethical barriers. Issues such as unequal access to digital infrastructure, high deployment costs, interoperability gaps, and concerns around data ownership must be addressed to ensure fair and reliable implementation. Developing lightweight security solutions for resource-constrained devices, advancing international interoperability standards through ethical frameworks would help to system to reach global users by improving its scalability.

Confilict of Interest

The authors declare no competing financial interest.

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