# A Survey of Internet of Medical Things (IoMT) Applications, Architectures and Challenges in Smart Healthcare Systems

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**Abstract.** Internet of Medical Things (IoMT) or Healthcare IoT is a technological under IoT catering to the healthcare sector. It refers to the interconnection of medical devices, sensors, applications and systems to the Internet. IoMT enables the collection, transmission and analysis of patient's data in real-time, allowing for remote monitoring and early detection of health issues. IoMT systems present a promising opportunity for prevention, prediction, and monitoring of emerging infectious diseases such as COVID-19. This paper provides a survey of IoMT devices, applications, benefits, challenges, and its impact on the healthcare industry.

**Keywords.** Internet of Things, IoT, Internet of Medical Things, IoMT, Healthcare IoT, Smart Hospital, Telemedicine, Fitness Tracker, Remote Patient Monitoring.

## 1 Introduction

Internet of Medical Things (IoMT) is a branch of IoT technology dedicated specifically to the healthcare sector. IoMT provides healthcare providers with continuous access to patients' health data, enabling them to monitor and manage chronic conditions, track medication adherence, and detect health problems before they become serious. IoMT has the potential to transform the healthcare industry by reducing healthcare cost and enhancing the patient's experience for healthcare [1]. By embracing IoMT systems, particularly for managing chronic illnesses, the healthcare sector has the potential to generate cost savings of up to $300 billion especially using telehealth. IoMT constituted 40% of the IoT market by the end of 2020 and the IoMT market is expected to grow to $254.2 billion in 2026 [2].

Unlike other IoT systems, IoMT systems have a direct impact on the lives of patients . IoMT systems present significant challenges like data security, privacy, interoperability, and regulatory compliance. Security of IoMT devices is a major challenge. For example, assaults on implantable devices like pacemaker can be life threatening. It is crucial to safeguard healthcare data in different stages within IoMT systems, including data acquisition, transmission, retention and storage. Healthcare industry experiences 340%

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more security incidents than any other industry and is 200% more likely to encounter data theft [3].

While the aim of IoMT systems is to reduce the overall healthcare costs, the costs associated with building the Healthcare IT infrastructure are enormous. The cost of the hardware, dedicated IoMT IT infrastructure, cloud computing, and creating consumer facing application result in a high initial investment cost. Even though the eventual return on investments is a definitive, the initial high infrastructure costs act as a barrier to IoMT.

## 2 IoMT Benefits

There are numerous benefits of IoMT in healthcare industry, including:

- **Remote patient monitoring**: IoMT enables consulting and monitoring patients remotely, thereby reducing the frequency of hospital visits.
- **Reduced healthcare costs**: By reducing the frequency of hospital visits and employing smart healthcare systems, IoMT reduces the overall healthcare cost.
- **Continuous monitoring of chronic disease patients**: IoMT enables continuous monitoring of patients with chronic diseases both in hospitals and remotely in their home. Instead of periodic check-ups or occasional assessments, continuous monitoring enables healthcare providers to collect up-to-date information on vital signs, symptoms, and other relevant health indicators. It facilitates effective communication between patients and healthcare providers, as they can discuss and address concerns based on real-time data.
- **Personal emergency response services (PERS)**: PERS can significantly reduce the response time in emergency situations. Immediate communication with the monitoring centre ensures that appropriate help is dispatched promptly, minimising the impact of injuries, complications and adverse health outcomes. Rapid intervention is especially critical in cases such as heart attacks, strokes and accidents where every second counts.

## 3 IoMT Architecture

A great number of IoMT architectures for healthcare systems are proposed with different layer formats by various researchers. Among them a predominant style for IoMT architecture is a four layer model.

Y. Sun et al [8] describe a 3 Tier architecture for IoMT based healthcare systems. Namely, tier1 which is the sensor level comprising of sensors and medical devices, tier 2 which deals with communication between sensor devices and coordinator and also data exchange between coordinator and medical server, and tier 3 which deals with data analysis.

A.H.M. Aman et al [9] propose IoMT pandemic specific architecture which consists of a 4 layer model as follows: IoMT device layer, IoMT communication network layer, IoMT platform layer, and IoMT application layer. In this paper researcher analysed and summarized various architecture models. C. Dilibal [10] proposes a 3 layer architectural model namely wearable device layer based on IoMT user interaction, edge computing layer and cloud layer for IoMT edge computing based architecture for health monitoring platform.

A.E. Khaled et al [15] provide an overview of 3-layer architecture for IoMT, such as the physical layer which deals with sensors and communication methodologies, the edge layer which performs data processing functions and real-time decision-making services, and the cloud layer which performs data processing, and data storage.

## 4 IoMT Devices

Sensors play an important role in IoMT ecosystem for data collection. Biological and physiological parameters of a human body are sensed by different types of sensors. These vital parameters are analysed by IoMT applications to provide healthcare services. In general, based on the usage, sensors are classified as wearable sensor devices, implantable sensor devices, and ambient sensor devices. Wearable or implanted biomedical sensors used to measure various physiological parameters of a human body like body temperature, breathing rate, blood pressure, blood oxygen saturation level, blood pressure, electrocardiography (ECG), electroencephalography (EEG), and electromyography (EMG). A. Ashfaq et al explain the various sensors used in healthcare ecosystem [16].

Fall detection and tracking application used for detect potential falls in the elderly and track them people and notify the guard if something is wrong [18].

Authentication, watermark, encryption, copyright protection, secure data transfer and more all apps fall into the category of data hiding [19].

In recent years, smart watches are very popular among all the age category people. Especially, after COVID-19 pandemic, people are more focused on their heath. Bio medical sensors attached with smart watches measures various health parameters depends on the sensors present in the device and also used as fitness trackers for example number of steps walked or number of kilo meters ran per hour, sleep tracking, fitness goal setting and many more.

A recent study by Fortune Business Insights™ titled, "Internet of Medical Things Market Size, Share & Industry Analysis, By Product Type (Stationary Medical Devices, Implanted Medical Devices, Wearable External Medical Devices), By Application (Telemedicine, Medication Management, Patient Monitoring, Others), By End User (Healthcare Providers, Patients, Government Authorities, Others) and Regional Forecast, 2019-2026," it is estimated that the IoMT market worldwide will experience a significant growth, expanding from $30.79 billion in 2021 to $187.60 billion in 2028, with a compound annual growth rate (CAGR) of 29.5% between 2021 and 2028.

Diabetes is serious chronic diseases, which affects the patents overall heath. Over longer period of time diabetes affects heart, kidney, nerves system and eyes. According to World health organization, worldwide 422 million peoples are affected by diabetics and in each year 1.5 million death are directly related to diabetics. The diabetic related IoMT devices/sensors like insulin pump, blood glucose monitoring devices like Glucometer provides continuously monitor the patients' glucose level. A.E. Khaled at all [15], classify medical and non-medical devices and sensors based on 6 different dimensions according to domains, type, data, device users' deployment scales, hardware and software capabilities of device.

Classification of various IoMT enabled healthcare devices are shown in the following figure.

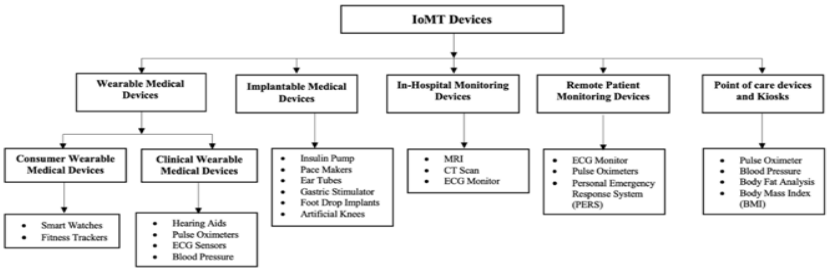


**Fig. 1.** IoMT enabled healthcare devices classification

As shown in the above figure, following are the types of IOMT devices:

**Wearable Medical Devices**: These are further classified as consumer wearable medical devices and clinical wearable medical devices.

*Consumer Wearable Medical Devices:* These are consumer devices like smartwatches and fitness trackers that are designed to monitor physical activity and provide insights to help users achieve their fitness goals. These devices include sensors that can track metrics such as steps taken, distance traveled, calories burned, heart rate and sleep pattern. Examples are smartwatches, wristbands and clip-on devices. They can be useful motivator for maintaining an active lifestyle.

*Clinical Wearable Medical Devices*: Clinical grade wearables are medical devices designed to be used in clinical settings like as hospitals. These devices have more accurate and reliable sensors that are designed to measure and monitor physiological parameters in a way that meets the standards of the healthcare industry. They can be used to monitor vital signs such as heart rate, blood pressure, temperature and oxygen levels.

**Implantable Medical Devices**: These devices are surgically implanted inside human body. These devices are made of biocompatible materials, such as titanium or ceramic, and are designed to integrate with the body's tissues without causing an immune response.

**In-hospital Monitoring Device**: Smart hospitals use in-house monitoring devices that are inter-connected to monitor patients' health conditions continuously. These devices are important for providing high-quality care to patients in critical care units and surgical wards.

**Remote Patient Monitoring (RPM) Devices:** RPM devices allow healthcare providers to remotely monitor patient's vital signs, such as blood pressure, heart rate, and blood glucose levels, physical activity and sleep patterns continuously in real-time. This enables healthcare providers to more easily analyze the changes in a patient's health condition, detect anomalies and quickly provide the needed remedy. RPM is an attractive option for healthcare providers and patients as it provides timely service, improves quality of care, reduced healthcare cost. Popular example for RPM devices are: thermometer, blood glucose monitoring devices, ECG monitor, pulse oximeter, weighing scales, spirometers.

**Point of care devices and Kiosks**: Point of care devices are used at the point of care such as clinics, urgent care centers and mobile health clinics to diagnose and monitor patients' health conditions. Examples of such devices are blood glucose meters, blood pressure monitors, pulse oximeters, and portable ultrasound machines. Kiosks are interactive self-service devices used in hospitals to streamline patients' workflow such as registration, appointment scheduling and preliminary health assessments. They are also used in public places to provide convenient access to healthcare services.

Thus, medical devices and sensors can be categorized based on their type, application, and range of capabilities, enabling the tracking of patients' physical well-being and remote monitoring of their activities and vital signs in real-time.

## 5 IoMT Applications

Following are typical IoMT applications:

**Smart Hospitals**: Smart hospitals are healthcare facilities that incorporate IoMT devices and technologies to improve patient care and optimize healthcare operations. These can include automated medication dispensers, remote monitoring devices, and other systems that help healthcare providers deliver more efficient and effective care.

**Remote Patient Monitoring:** Remote patient monitoring (RPM) involves the use of medical devices to monitor patients outside of traditional healthcare settings, such as at home. RPM devices can include blood pressure monitors, blood glucose meters, and other vital sign monitors that can send data to healthcare providers for analysis.

**Telemedicine:** Telemedicine refers to the use of technology to provide healthcare services remotely. With telemedicine, patients can connect with healthcare providers using video conferencing and other digital communication tools, allowing them to receive medical advice and treatment without leaving their homes.

**Medical Imaging:** IoMT can also be used to improve medical imaging, such as X-rays and MRIs. Medical imaging devices can be connected to the internet to transmit images to healthcare providers for analysis and diagnosis.

**Health and Wellness Apps:** Health and wellness apps are mobile applications that can be used to track and manage various aspects of a user's health, including diet, exercise, and sleep. These apps can connect to wearable devices and other IoMT technologies to provide users with real-time data on their health and wellness goals.

Overall, IoMT applications have the potential to improve healthcare outcomes, increase patient engagement, and optimize healthcare operations.

## 6 Security in IoMT

IoMT devices face a range of security challenges, including:

**Patient data privacy:** IoMT devices often collect sensitive patient data, such as health records and biometric data. This data needs to be protected from unauthorized access or disclosure, as it can be used for identity theft, financial fraud, or other malicious purposes.

**Device authentication**: IoMT devices need to be able to authenticate with the network and other devices to ensure that they are legitimate and not being controlled by malicious actors.

**Device integrity:** IoMT devices need to be protected against tampering or unauthorized access to ensure that they are functioning as intended and not being used to collect or transmit false data.

**Network security:** IoMT devices are often connected to a network, which can be vulnerable to attacks such as denial of service (DoS) attacks or ransomware.

**Regulatory compliance:** Many IoMT devices are subject to regulations and standards, such as HIPAA (Health Insurance Portability and Accountability Act), which require organizations to implement appropriate security measures to protect patient data.

To address these challenges, organizations need to implement a range of security measures. These include:

**Encryption:** Data should be encrypted both in transit and at rest to protect it from unauthorized access.

**Access controls:** Access to IoMT devices and data should be restricted to authorized personnel only.

**Authentication and authorization:** Devices should be authenticated and authorized before being allowed to connect to the network or other devices.

**Regular updates:** IoMT devices should be regularly updated with security patches and software updates to ensure that they are protected against known vulnerabilities.

**Monitoring:** Organizations should monitor their networks and devices for suspicious activity and respond to security incidents in a timely manner.

## 7 Challenges in IoMT

IoMT enabled healthcare systems have transformed traditional health care systems. The advantages of IoMT systems are discussed in the introduction part. The IoMT eco system consist of data collection, data pre-processing, data forwarding, and data analysis. There are many challenges to be focused while developing and deploying IoMT system. Some of those challenges are:

- High infrastructure cost
- Real time processing of sensor data
- Power Consumption
- Interoperability of data
- Regulatory challenges
- Standardization issues
- Data security and privacy
- Data storage
- Software upgrade

S. Selvaraj et al [17] list out the challenges related to data privacy and sensor device's energy consumption in healthcare IoT.

## 8 Conclusion

IoMT is a rapidly growing field that has the potential to revolutionize healthcare. IoMT devices and technologies allow healthcare providers to remotely monitor patients, analyse patient data, and provide personalized care. This has become particularly important during the COVID-19 pandemic, as healthcare providers seek to minimize in-person visits and reduce the risk of infection. IoMT has several benefits, including improved patient outcomes, reduced healthcare costs, and increased access to care. It has many use cases, including remote patient monitoring, telemedicine, chronic disease management, and predictive analytics. However, there are also several challenges associated with IoMT, including data security and privacy concerns, interoperability issues, and the need for standardization.

Despite these challenges, the IoMT market is expected to continue to grow rapidly in the coming years. Major players in the market include tech giants such as IBM, Apple, Google, and Microsoft, as well as medical device manufacturers such as Medtronic, Philips, and Abbott Laboratories. The increasing adoption of wearable devices and other IoMT technologies is expected to drive this growth, along with advances in data analytics and machine learning.

Overall, IoMT has the potential to transform healthcare by improving patient outcomes, reducing costs, and increasing access to care.

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