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Applications for the Internet of Medical Things

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Abstract

IoMT has revolutionized healthcare by integrating advanced technologies to enhance patient monitoring, diagnosis, and treatment. This paper explores the applications associated with IoMT, including its role in remote health monitoring, intelligent disease diagnosis, infectious disease tracing, and smart hospital management. IoMT enables real-time data collection and analysis through interconnected medical devices, improving healthcare efficiency and accessibility. This review provides insights into the current advancements in IoMT.

Keywords: Internet of Medical Things (IoMT); Remote patient monitoring; Intelligent diagnostics; Smart hospitals; Telemedicine; Health informatics

1. Introduction

Health is a common goal pursued by all human beings. and safeguarding public health is the primary responsibility of medical systems [1], [2]. Advancements in modern technology have significantly enhanced medical techniques and healthcare practices. Physicians today have access to cutting-edge diagnostic instruments and more effective treatments, improving their ability to combat diseases and protect people's well-being [3], [4]. On the other hand, despite these advancements, healthcare systems continue to face immense challenges [5]. Severe illnesses such as cancer and cardiovascular diseases remain major threats to human health. Additionally, infectious diseases like AIDS continue to pose significant challenges, with no definitive means of eradication [6]. The recent coronavirus pandemic has further exposed the vulnerabilities of modern healthcare systems in handling large-scale public health crises [7]. As a result, there is an urgent need for technological innovations to develop new methods for disease prevention and treatment while strengthening the resilience of healthcare infrastructures [8], [9]. Researchers are actively exploring ways to leverage these technologies to enhance the efficiency and capacity of medical systems to better serve populations worldwide.

In recent years, the Internet of Medical Things (IoMT) has emerged as a transformative technology in the healthcare industry. IoMT refers to a network of interconnected medical devices and systems that collect, analyze, and transmit health data, enabling remote patient monitoring, diagnosis, and treatment. This innovation is reshaping healthcare delivery by improving accessibility and efficiency. To understand the development of IoMT, it is essential to revisit the broader concept of the Internet of Things (IoT) [10], [11], [12]. Unlike the traditional internet, which primarily connects people, the IoT extends connectivity to various physical entities, including both people and objects. Any independently identifiable entity can serve as a node within the IoT, making its value stem from interconnections between objects rather than human interactions alone.

IoT has made significant strides across multiple industries, including smart transportation, smart cities, smart factories, and smart homes. In a smart city, for example, citizens, city managers, infrastructure, and buildings are integrated into a shared IoT platform. Every streetlight, traffic camera, and first aid station functions as a data-collecting node,

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contributing to the city's overall efficiency and functionality. Similarly, IoMT applies this interconnected framework to the healthcare sector, enabling real-time monitoring, automated diagnostics, and improved medical interventions, ultimately enhancing patient outcomes and optimizing healthcare resources.

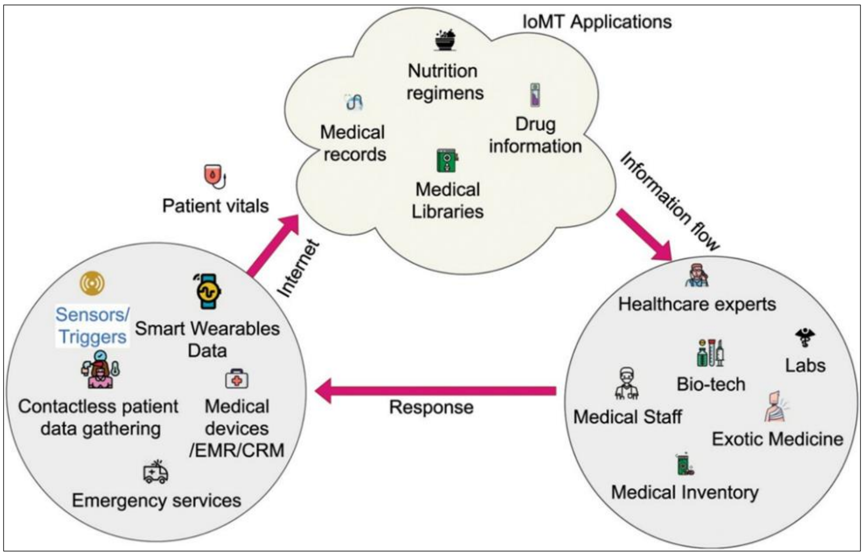

Figure 1 Internet of medical things (IoMT) [14]

2. IoMT

IoT systems consist of sensors and devices connected via a network of cloud ecosystems over high-speed connectivity between each module. The raw data collected at these devices/sensors is sent directly to the vast storage offered by cloud services. This data is further cleaned and then analyzed to gain further insights into it. This requires additional software, tools, and applications which will further assist in visualization, analysis, processing, and management of the data.

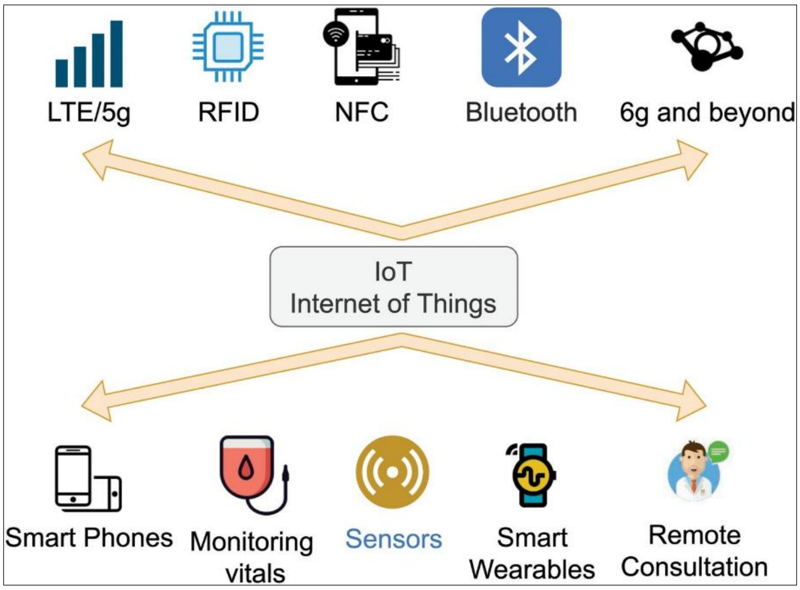

Figure 2 Internet of things, enabling technologies and devices [14]

Figure 2 shows several wireless technologies such as RFID (Radio Frequency Identification), NFC (Near Field Communications), Bluetooth, LTE (Long Term Evolution) and 5G/6G (and beyond) inter-linked with several devices such as smartphones, monitoring devices, sensors, smart wearable, and other medical devices. Currently, the use of 5G/6G or beyond is prevalent in IoMT due to their high bandwidth and ultra-low latency benefits.4

3. Common Types of IoMT Devices

IoMT devices span a wide range of categories, including:

a) **Consumer-grade wearables** – Smart devices that include Fitbit and other fitness monitors, activity trackers, and Apple watches, among others.
b) **Medical-grade wearables** – Regulated, clinical-level products that are used under the guidance of a clinician, including devices designed to manage pain, improve physical performance and resolve other health issues.
c) **Remote patient monitoring (RPM) devices** – Systems that help manage chronic diseases, usually placed in the homes of patients who are undergoing long-term care.
d) **Personal emergency response systems (PERS)** – Wearable devices that allow a patient, often a senior, to quickly call for help to a care provider in an emergency.
e) **Smart pills** – An emerging category of devices that can be swallowed by a patient, wirelessly transmitting data about a patient's internals to medical providers.
f) **Point-of-care devices and kiosks** – Mobile devices, ranging from ultrasound machines to blood glucose meters, that can obtain diagnostic information and other health data — whether they are in a doctor's office or in the field — without the need for a full laboratory.
g) **In-clinic monitors** – Similar to point-of-care devices, except that they can be managed remotely, without the need for an expert care provider on-site.
h) **In-hospital devices** – A large segment of devices, including MRI machines, used to track hospital assets, monitor patient flow, track inventory (such as pharmaceuticals), and manage other hospital resources.

4. Applications

4.1. Remote Health Monitoring

The Internet of Medical Things (IoMT) has been widely applied in remote health monitoring due to its advantages in connectivity, convenience, and intelligence. Ghosh [15] introduced a health monitoring system that allowed doctors and guardians to remotely monitor a patient's health status. Building on this, a cost-effective health monitoring device based on Raspberry Pi 3 was developed in [16], making it particularly useful for healthcare in rural areas. Gupta [17] proposed a machine learning-based method to predict disease prevalence using medical data collected from underserved regions.

Other researchers have leveraged advanced sensing and signal processing technologies. Sacco et al. [18] developed a radar-based indoor positioning and breath monitoring system, achieving high accuracy. An ECG remote monitoring approach was introduced in [19] using maximal overlap discrete wavelet transform, while [20] applied fog computing and a Bayesian belief network to improve decision-making speed and accuracy in remote health monitoring systems.

The effectiveness of wearable devices has also been explored. Durán-Vega et al. [21] deployed a real-time health monitoring bracelet for elderly communities, incorporating sensors for heart rate, temperature, and blood oxygen levels. Other researchers developed similar multi-sensor systems; Hamim et al. [22] combined heart pulse, body temperature, and galvanic skin response sensors into a single system using Arduino Uno and Raspberry Pi boards, complemented by an Android application.

Machine learning techniques have further enhanced remote health monitoring. Kaur et al. [23] built an IoMT-based disease prediction system trained on public health datasets, comparing KNN, SVM, decision tree, random forest, and MLP models. Nguyen et al. [24] developed a mobile cloud system to monitor neurological disorder progression, demonstrating acceptable performance.

Recent advancements have focused on computational efficiency. Ç, D. [25] designed an edge computing framework to process real-time video footage from IoMT systems. Khan et al. [26] introduced a heart disease diagnosis system using the Adaptive Neuro-Fuzzy Inference System (ANFIS), enhanced by a modified salp swarm optimization (MSSO) algorithm, achieving outstanding predictive accuracy. Wang et al. [27] developed a millimeter-wave radar-based fall detection system, incorporating a line kernel convolutional neural network (LKCNN) to analyze baseband data.

The integration of next-generation technologies has further expanded remote healthcare capabilities. Zhang et al. [28] implemented a remote monitoring system using mobile edge computing and 5G. Parvathy et al. [29] developed a health monitoring system for rural India using the CHAID algorithm. Deep belief networks were applied in [30] for heart disease monitoring.

4.2. Intelligent Disease Diagnosis

IoMT has also been widely applied in disease diagnosis, integrating intelligent algorithms, telemedicine, and IoMT infrastructure. Bibi et al. [31] proposed a leukemia subtype identification method using DenseNet-121, outperforming conventional machine learning methods. Han, T. et al. [32] applied deep learning segmentation models for lung CT and hemorrhagic stroke CT, achieving 99% segmentation accuracy and a Dice coefficient above 97%. Souza et al. [33] used Mask R-CNN combined with Parzen's probability density for lung CT segmentation, delivering state-of-the-art performance.

IoMT has been instrumental in COVID-19 detection. Ahmed et al. [34] employed Faster R-CNN for chest X-ray-based COVID-19 detection, achieving 98% accuracy. Tai et al. [35] introduced a COVID-19 diagnosis framework combining VR/AR, 5G cloud computing, deep learning, and Copycat networks.

Other disease detection applications include brain tumor identification. Khan, S. R. et al. [36] used the partial tree algorithm for brain MRI image analysis. Chidambaranathan, S. et al. [37] proposed an IoMT-based classification method using the Improved Gravitational Search Algorithm with Genetic Algorithm (IGSAGA), demonstrating superior performance. Xu, Y. et al. [38] developed a classification method for uninjured and hemorrhagic stroke using skull CT images.

Further advancements include cardiac disease monitoring. Pan, Y. et al. [39] introduced an Enhanced Deep Learning-Assisted Convolutional Neural Network (EDCNN) for heart disease diagnosis on IoMT platforms, achieving 99.1% accuracy. Ning et al. [40] proposed a hybrid IoMT-based model combining CNNs and RNNs for congestive heart failure detection.

Additionally, Raj et al. [41] developed a classifier for lung cancer, brain imaging, and Alzheimer's disease using the opposition-based crow search (OCS) algorithm. Khamparia, A. et al. [42] introduced an IoMT-driven skin cancer detection system using SqueezeNet. Wang et al. [43] applied a fully dense UNet architecture for IoMT-based liver cancer diagnosis, while Xuan et al. [44] proposed a hierarchical CNN-RNN model for pancreatic cancer detection.

4.3. Infectious Disease Tracing

IoMT plays a vital role in infectious disease tracing, particularly during pandemics [45]. Since 2017, researchers have developed numerous IoMT-based solutions to control disease spread. An infrared-based system was developed in [46] for fever detection and movement tracking. During the COVID-19 pandemic, Wei et al. [47] introduced a low-cost facial temperature estimation system, while Aufar et al. [48] presented a non-contact facial temperature measurement method using long-wave infrared (LWIR) cameras.

Beyond temperature detection, IoMT has been used for patient identification and tracking. Tan et al. [49] designed a facial recognition-based COVID-19 patient tracking system, while Wang, Z. et al. [50] developed a deep learning-based masked facial recognition model with 95% accuracy. Hariri [51] improved this approach by incorporating occlusion removal and ResNet-50 for feature extraction.

4.4. Smart Hospitals

The integration of IoMT in smart hospitals has vast potential. Udawant et al. [52] developed an ambulance management system, 'Green Corridor,' which automated traffic light control to prioritize emergency vehicles. Boutros-Saikali et al. [53] created an IoMT platform to facilitate hospital application deployment. IoMT has also been applied to drug management. Jamil et al. [54] introduced a blockchain-based pharmaceutical supply chain management system to reduce counterfeit drugs and drug abuse. During the COVID-19 pandemic, IoMT-driven automation became critical. Nosirov et al. [55] developed an autonomous disinfection robot, while Nagarajan et al. [56] applied deep learning for hospital data mining and management.

ML models were used in [57] for COVID-19 diagnosis and IoMT-powered crowd control system was used in [58] to prevent excessive gatherings in hospitals. Ktari et al. [59] designed an IoMT-based health monitoring system using Raspberry Pi 4 and multiple sensors.

4.5. COVID-19 Management

The COVID-19 pandemic has played the role of catalyst in the innovation of medical technologies, particularly IoMTs. IoMT utilizes existing network and cloud technologies to establish connections with medical equipment and healthcare devices. IoMT technology and medical devices or equipment like smartwatches can remotely transfer critical health parameters for further data management processes. Hence, IoMT has played a significant role in tracing, monitoring, and treatment of COVID-19 patients thus aiding healthcare workers in COVID-19 management [60-65]. Hospitals and healthcare facilities have limited capacity to manage and provide treatment to all under intense pressure of the COVID-19 epidemic. IoMT facilitates healthcare professionals in remotely accessing accurate and vital health parameters of patients, performing diagnostic tests accurately & immediately, performing treatments, and monitoring health status in real-time. The phenomenal growth of IoMT is fueled by the progress made through the miniaturization of silicon devices, digital signal processing techniques, artificial intelligence, big data, machine learning, and customization of underlying embedded devices [66-75]. These advancements have led to better and more efficient management of data that enables medical professionals to receive data about critical scenarios and suggest solutions in real time.

5. Conclusion

The integration of IoMT technologies enables real-time health tracking, early disease detection, and improved healthcare efficiency. Despite its promising benefits, the widespread implementation of IoMT is hindered by challenges such as cybersecurity threats, interoperability issues, and regulatory constraints. Addressing these challenges requires advancements in secure data management, improved communication protocols, and robust legal frameworks. Future research and technological innovations should focus on refining IoMT infrastructure, enhancing AI-driven healthcare analytics, and ensuring seamless integration into medical ecosystems

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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