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A Comprehensive Review of the Internet of Medical Things in Healthcare

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***Abstract*—The continuous and rapid development in Internet of Medical Things (IoMT) technologies has led to the expansion of their applications in the field of healthcare and to increased interest in developing their technologies for the purpose of improving their performance in light of the challenges facing their practical application. This paper aims to provide a comprehensive up-to-date review of the literature on IoMT and telemedicine. The study discusses the growing interest in the Internet of Things (IoT) in healthcare, emphasizing the IoMT. It highlights the significance of the IoMT in intelligent healthcare systems, particularly in pandemics like COVID-19, where remote monitoring becomes crucial. This study examines the utilization of the IoMT systems, emphasizing on the application of sensors in healthcare industry. Furthermore, it highlights the significance of cloud computing, communication technologies, artificial intelligence, and Blockchain in IoMT. The challenges related to accepting IoMT in practice are explored; including data security, integration of protocols, data overload, accuracy and cost. Overall, the analyzed literature confirms that IoMT-based healthcare systems demonstrate significant potential in delivering comprehensive surveillance and immediate monitoring through public catastrophes.**

***Index Terms*—IoMT, IoT, healthcare, Remote patient monitoring, telemedicine, blockchain**

I. INTRODUCTION

The world is increasingly adopting the Internet of Things (IoT) technology, which enables the seamless transmission of substantial volumes of data, irrespective of location and temporal constraints. This feature allows for remote control and more convenient, intelligent, and effective monitoring of objects [1]. IoT has been expanded to intricate and accurate systems in several sectors, particularly in managing factories, city surveillance, and medical applications [2]. Smart healthcare systems can benefit from the next iteration of the IoT, known as the Internet of Medical Things (IoMT). It provides facilities that enable healthcare professionals to monitor and treat patients remotely and effectively [3]. The IoMT is a promising technology in healthcare and telemedicine systems. Outdoor and interior environments may be continuously monitored with IoMT-based technologies. Remote monitoring has radically altered the healthcare system by linking previously inaccessible areas. A remote monitoring system becomes more essential during public health crises such as the COVID-19 pandemic to remotely assess patients and prevent the virus spread [4]. The deployment of the IoMT has enhanced the intelligence of sensors, enabling them to engage in interactions, collaborations and the sharing of experiences. IoMT minimizes the need for human involvement and aids in making prompt decisions. IoMT-based telemedicine is an emerging concept in the healthcare sector [5]. Telemedicine has emerged as a prominent technical advancement in the medical field, gaining significant popularity in recent years. Telemedicine aims to provide healthcare services to individuals who are geographically far from medical institutions [6].

However, pandemic circumstances also lend themselves to telemedicine, as patients are advised to stay away from hospitals until necessary. The field of health is undergoing fast changes, and new technologies have the potential to provide health professionals with more effective tools [7]. Often, patients receiving care at home face challenges in receiving timely medical attention due to a delay in recognizing the presence of an underlying issue, leading to the development of severe complications. To address this health issue, remote patient health monitoring systems have been developed to enable the remote monitoring of an individual’s health status on portable devices, such as mobile phones or tablets, that have internet connectivity [8]. Moreover, providing care for post-operative patients is a laborious and costly responsibility for hospitals. While many patients are deemed fit for discharge, they still require close monitoring due to potential complications and dangers that could be detrimental to their well-being. IoMT may also be utilized for continuous health monitoring for older household individuals and similar cases [9].

Therefore, IoMT technologies have received a great interest and are being continuously developed to improve the effectiveness and efficiency of healthcare and telemedicine systems. This paper aims to offer a comprehensive review of IoMT systems based on the available literature. Firstly, the methodology of selecting the references is given in Section II. Then, based on the selected references, the paper presents a review for the architecture and categories of IoMT in Sections III and IV, respectively. The works that explore the effectiveness and improvement of the components and technologies of IoMT are presented in Section V. The challenges that

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encounter the successful application of IoMT are presented in Section VI. Finally, conclusions, future directions and emerging trends of IoMT are given in Section VII.

II. METHODOLOGY

Despite all the disadvantages and losses that the world has witnessed as a result of the Corona pandemic, the pandemic has contributed in one way or another, to stimulating research activity in the field remote healthcare systems. More specifically, it increased the interest in IoMT and accelerated its development. So the focus in this research is made on scientific researches and articles published by reputable publishers such as IEEE institutions and others, with more focus on the period from 2019 to 2024. By applying these criteria, 64 references were selected from the large number of researches available in the literature, for the purpose of presenting the up-to-date IoMT-related techniques, trends and recommendations.

III. ARCHITECTURE OF IOMT SYSTEMS

Generally, the architecture of the majority of the current IoMT systems can be demonstrated as a stack of four distinct layers, as depicted in Fig. 1 [10]. The layers comprise the whole process of integrating data, all the way from collecting an individual’s biometric information to storing data. The data is then visualized by a physician for analysis [11]. The main role of each layer may be summarized as follows:

- *Layer of Sensors:* This layer gathers biometric data from the patient via a network of tiny sensors that are either worn or implanted. Wireless technologies like internet connection and Bluetooth technology [11] or the MedRadio frequency spectrum set aside for implantable medical devices [12] carry the data to the second layer.
- *Gateway layer:* It receives the raw data without processing it since the IoMT sensors have limited processing and storage capacity. At this level, the patient’s mobile phone or an access point is often more robust than sensors. They can do fundamental Artificial Intelligence (AI)-based analysis, short-term data storage, and validation as part of their preprocessing activities. In addition, the Internet is utilized for the purpose of uploading the sensor data to the cloud [11].
- *Cloud Layer:* The cloud layer retrieves data from the gateway for storage, analysis, and secure access. The analysis may include the processing of data to identify any alterations in the patient’s health condition, which are then presented to the health care providers or patients for further interventions. The primary function of the key generation server is to generate unique identifiers (IDs) and cryptographic keys for multiple system nodes. The management and control of sensor access may be facilitated remotely using this particular layer [11].
- *Visualization/Action Layer:* This layer displays data to doctors and patients to monitor their health. This layer encompasses the interventions suggested by the physician in response to the patient’s medical circumstances. Instances of action include prescribing or modifying various medicines’ doses [11].

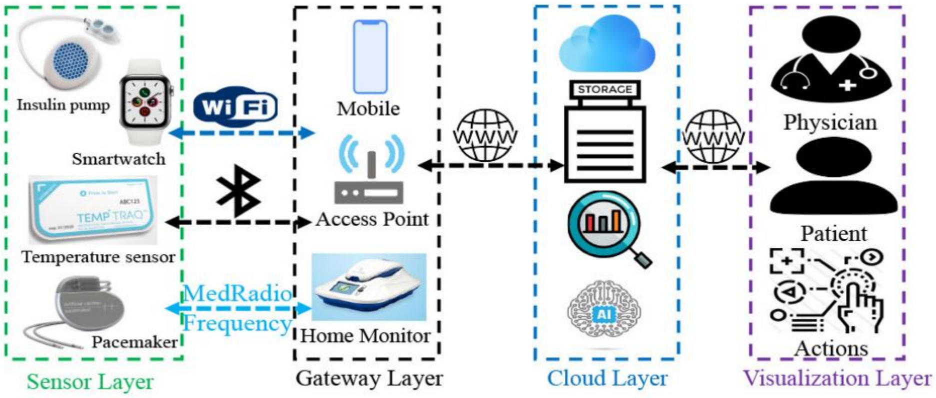

Fig. 1. IoMT system architecture [11].

IV. CATEGORIES OF IOMT

The utilization of IoMT systems can facilitate the treatment of various medical conditions by offering an efficient means for improved diagnostics and therapies. The IoMT can revolutionize the healthcare sector by optimizing labor productivity, facilitating remote monitoring and diagnostics, and enhancing patient care. The basic structure of IoMT networks is generally the similar, but there are differences in the way they are applied and used, according to which IoMT systems may be classified in to different categories. That is, from the point of view of how the medical sensors and devices are attached to the body of the patient, IoMT is conventionally classified into two categories: IoMT with medical devices implanted into the body and IoMT with wearable devices [13].

A. *IoMT with Implanted Medical Devices*

Implantable medical devices and sensors are sophisticated instruments that can be surgically placed inside the human body to identify, track, and manage illnesses. These devices are commonly implanted through surgical procedures or put into the body using minimally invasive approaches. They may carry out specialized activities and provide immediate medical assistance, depending on the needs of the individuals [13].

Examples of IoMT implanted medical devices include: Various modalities of implantable medical devices (IMDs), such as cochlear implants, pacemakers, artificial hearts, insulin pumps, bone growth stimulators, retinal implants, neuro-stimulators, cardiac defibrillators, and medication pumps, are widely used and clinically validated in the field. Fig. 2 [14] presents a visual representation of the IMDs, illustrating their specific anatomical positions throughout the human body. In order to improve healthcare in the near future, the effective adoption of these IMDs depends on their ability to be compact and self-sufficient in terms of energy [15].

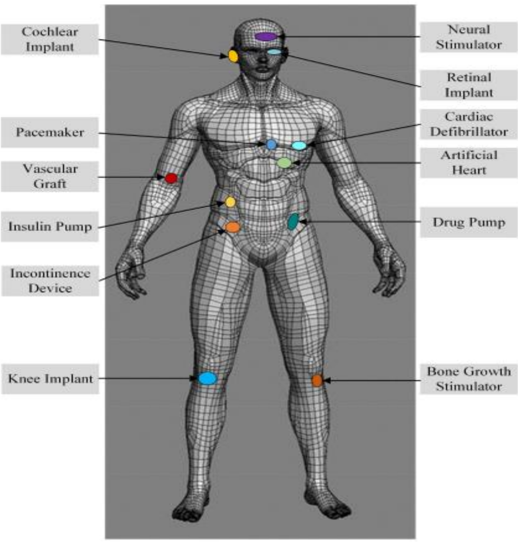

Fig. 2. IMDs and their respective anatomical positions inside the human body [15].

Wireless implantable medical devices are essential in modern healthcare because they offer several advantages and benefits by allowing real-time monitoring, data collecting, and remote management of implanted medical equipment. Furthermore, these devices enhance patients' mobility and comfort by eliminating the need for wires or physical connections. Therefore, for these gadgets to continue functioning within the human body for a long time, they need to have small batteries that consume very little power, have a limited storage capacity, and have a long lifespan [13].

B. *IoMT with Wearable Devices*

These gadgets facilitate remote health monitoring and possess the potential to have a beneficial influence on individuals' health. Examples of IoMT wearable devices include Wearable Cardioverter Defibrillators (WCDs) that can be worn [16]. These procedures provide life-saving measures for those with irregularities in cardiac rhythm. Wearable technologies such as smart bands [17], smart gloves [18], and smartwatches [19] facilitate the ongoing monitoring and tracking of health, hence facilitating proactive management of healthcare. Wearable spirometers play a vital role in the monitoring of lung function, particularly among persons with respiratory diseases [20]. Electrocardiogram (ECG) patches [21] provide a non-invasive method for capturing electrocardiogram data over prolonged durations, hence facilitating the identification of heart abnormalities. These patches have the potential to be created as very thin electronic tattoos, enabling measurements in many scenarios. Insulin pumps [22] and Continuous Glucose Monitors (CGMs) [23] have greatly enhanced the quality of life for those with diabetes by providing accurate regulation of glucose levels and decreasing the need for regular blood sugar monitoring. In the context of pain treatment, Transcutaneous Electrical Nerve Stimulation (TENS) therapy devices [24] are used to provide focused electrical stimulation with the aim of mitigating pain.

Additionally, wearable photoplethysmography (PPG) sensors, as described in [25], have the capability to monitor the human heartbeat by extracting it from the blood flow inside the cardiovascular system. The incorporation of wearable medical devices (WMDs) into garments enables the integration of smart textiles for the purpose of recording vital signs and electrocardiogram data [26, 27]. Furthermore, the use of intraoral cameras [28] has been shown to improve dental care by enabling dentists to acquire high-resolution pictures of oral health conditions, hence facilitating precise diagnosis and treatment regimen development. In general, IoMT devices have a significant influence on several aspects of healthcare, including cardiovascular health, chronic illness management, pain alleviation, and dental treatment. Ultimately, these devices have a role in improving the quality of life for patients and increasing the efficiency of healthcare [29].

These wearable devices provide continuous healthcare monitoring, promoting preventive care and early intervention. These devices incorporate sensors for photoplethysmography, electromyography, electroencephalography, electrocardiography, skin temperature, and blood oxygenation. Wearable gadgets necessitate suitable sensors for the detection of diverse ailments. To ensure the comfort of wearable technology, the product's dimensions, form, and thermal qualities must be within an acceptable range. Nevertheless, these devices are subject to constraints in terms of sensor precision and duration of battery usage [30]. However, one of the brilliant deployments of wearable devices is the use of the wearable smart blanket system [31, 32]. It can eventually allow monitoring of the subjects in a timely manner. This system also allows communication with the physicians at the health center so that the emergency technician could receive specific medical and diagnostic advice when the need arises.

V. IOMT TECHNICAL COMPONENTS

A. *The Sensing Devices*

Biomedical sensors have seen widespread use in continuous and real-time health monitoring through their integration into IoMT devices. Typically, these sensors can be classified into two classes according to their general duty. The first class includes physiological sensors, which measure the patient's heart rate, blood pressure, and various other body metrics. The second class consists of environmental sensors, which gauge parameters surrounding the patient, including air quality, humidity and temperature.

IoMT sensors have been the subject of many researches in the literature to study and improve their characteristics and performance. That is, in [33] an IoT system has been designed to monitor the health of individuals with chronic conditions in real time. The system utilized widely available hardware components such as pulse, temperature, and saturation peripheral oxygen (SpO2) sensors. The system has demonstrated encouraging outcomes in continuously monitoring patient vital parameters and sending alerts to doctors if values exceed thresholds, enabling prompt medical intervention and exhibiting potential for further advancement in healthcare environments.

The characteristics of the micropyramid-assisted piezoelectric film (MPF) sensors were investigated in [34] for continuous, noninvasive real-time blood pressure monitoring. The study explored their performance through experimental testing and finite-element modeling simulations. The obtained results indicated that MPF sensors, particularly those with polydimethylsiloxane micropyramids covered with Ecoflex, exhibit high sensitivity (685 mV N^{-1}) within a range of 50 to 400 mN. MPF sensors, which are worn on the wrist and neck to detect pulse pressure signals, allow blood pressure to be estimated and hold potential for preventing cardiovascular disease.

In the context of the problem of restricted availability of professional healthcare services in rural regions, mostly due to geographical distance and a scarcity of medical practitioners, the real-time operation of IoMT was considered in [35]. The IoT-based real-time remote patient monitoring system effectively transferred ECG data using the AD8232 sensor without any loss or mistakes in both Local Area Network (LAN) and Wide Area Network (WAN) scenarios. The system demonstrated identical ECG values between the sender and subscriber during the experiments, confirming the absence of any packet faults. The performance in the public network was approximately tenfold higher than in the private network, with an acceptable delay of 50.08 ms in the public network.

However, the effect of shortage of healthcare infrastructure on telemedicine systems was addressed in [36]. Such shortages of healthcare infrastructure in remote regions, specifically rural areas in India, are due to the scarcity of healthcare professionals. The proposed system to tackle the research problem, comprised both hardware and software components. The system consists of sensors such as the linear monolithic temperature sensor (LM35) and pulse sensor, a popular Arduino UNO board, and a Node MicroController Unit (NodeMCU) to acquire and transmit data. The system offers a non-intrusive and effective solution for remote health monitoring.

Next, the experimental work presented in [37] highlighted the surveillance of body temperature patients via integrated infrared sensors and WiFi connection in a system based on the IoT. The prototype showcases precise temperature measurements and recommends the most influential body areas for temperature monitoring. The proposed Remote Patient Body Temperature Monitoring (RPBTM) device showed an error of only 0.56% compared to the standard device, with positive relationships between body parts like the forehead and armpit. Experimental results compared body temperature measurements of the forehead, palm, and armpit, showing differences between body parts and temperature ranges for different age groups. The RPBTM system aimed to reduce infection risks for medical staff during the COVID-19 pandemic, providing real-time monitoring and efficient data storage for medical personnel.

The collected data archiving and access security were studied in [38]. The concept has been applied to an economical and simple method for measuring pressure and temperature using open-source development boards, FlexForce sensors for pressure measurement on the feet, and DHT11 sensors for temperature measurement. The device offered instantaneous data for those with diabetes and neuropathy, promoting a well-balanced way of life and remote monitoring of health. The paper presented a real-time cloud monitoring system for foot pressure and temperature to prevent ulceration and fatalities in diabetic patients. The system can store 30 days of data in the cloud with end-to-end security measures. Thresholds were set using the Toronto Clinical Scoring System (TCSS) and pressure ratios to provide real-time monitoring and alerts to healthcare facilities. The presented analysis showed that patients with diabetic neuropathy have higher foot temperatures and peak pressures compared to those without neuropathy.

The integration of machine learning into the IoMT was considered in [39]. It examined the need for remote patient monitoring during the COVID-19 pandemic. It utilized wearable sensors to gather vital sign data. The technology prevents the need to document critical sign data manually. The paper extended a previous IoT-based healthcare platform to include wearable and unobtrusive sensors for monitoring COVID-19 patients in an ICU in Brazil. The platform was successfully deployed in a real ICU setting, showcasing the feasibility of remote monitoring for critical patients. The study aimed to attract interest in expanding research on continuous health monitoring supported by unobtrusive sensors, with future plans to integrate machine learning algorithms for predicting risky events and enhancing treatment effectiveness.

A related study [40] presented an intelligent solution that utilized IoT technology to aid individuals experiencing influenza symptoms in ascertaining their COVID-19 infection status. The technology facilitates rapid medical treatment and patient movement monitoring to assess questionable behaviors, with possible applications in medical facilities, quarantine units, and airports. The sensors used in this work were a temperature and humidity sensor DHT, sound microphone sensor, and GPS NEO unit connection. The system showed a reliable performance in terms of accuracy and real-time operation.

The accuracy of the acquired data was evaluated in [41]. It presented the development of a tool to monitor health conditions remotely, providing data on body temperature, oxygen levels ($SP0_2$), and heart rate (BPM) through Android apps and internet-connected web servers. The tool showed an average error value of 1% when testing oxygen levels within the tolerance limit, enabling its use for analyzing patient conditions remotely and aiding in treatment decisions. A comparison of readings between the device with a MAX30100 sensor and the honor band 5-pulse oximeter showed slight variations in the results of reading oxygen levels in the blood. As compared with locally measurements from standard devices, the remote obtained patient readings had showed an acceptable accuracy.

B. Cloud Computing

The conventional IoMT encounters challenges in establishing interconnections among numerous medical institutions and their respective medical information systems. Consequently, this leads to the formation of isolated medical service information islands, resulting in the generation of redundant data during the medical process. This, in turn, leads to significant resource wastage and exacerbates the issue of interoperability between medical systems of information. Furthermore, the information structure of extensive health-related information is diverse and intricate, necessitating enhanced capabilities for information storage, processing, and administration. The leaking of extremely sensitive medical data will have a significant effect on people, families, and society since it not only compromises patients' privacy but also impacts illness control, informed decision-making, and other related issues. Traditional IoT has challenges in guaranteeing the security, privacy, and integrity of large amounts of data. The medical domain has witnessed remarkable developments in the utilization of cloud computing technology within the IoMT in recent years. These advancements can be attributed to the prominent qualities of cloud computing, including high reliability, sharing capabilities, and scalability. The medical domain is currently undergoing an increase in intricacy as a result of the swift progression of contemporary research and technology, alongside the advent of big data and the information era. Consequently, there has been a rise in the diversity of medical data, which presents notable difficulties in terms of accessing data, processing information, and maintaining the system.

Cloud-enabled IoMT is being applied. Utilizing cloud computing for medical information building significantly mitigates the scarcity of medical resources, lowers the expenses associated with patients' medical care, and enhances the quality and effectiveness of medical services. The fundamental objective of the medical cloud IoMT is to develop a platform for exchanging medical information, using electronic health records. This platform aims to address the issue of information fragmentation among various medical institutions. The uploading of electronic health files, which include personal information, vital signs, and other pertinent patient data, to cloud for storage and unified administration has significant value for both hospitals and patients [42].

Furthermore, telemedicine [43] represents a significant avenue for the use of cloud computing within the medical domain. The implementation of the pay-as-you-go service model significantly decreases the expenses associated with acquiring and upkeeping the necessary gear for telemedicine, hence enhancing the effectiveness of telemedicine. Simultaneously, this technology addresses the issue of geographical distance, enabling patients residing in remote or economically disadvantaged regions to access expert consultation through the transmission of images or real-time videos. Consequently, they can receive treatment and nursing care under the guidance of healthcare professionals, thereby enhancing the standard and efficacy of patients' medical care and potentially preserving their lives.

In addition, the field of telemedicine also encompasses the safeguarding of patient health data [44]. Cloud enables the storage, analysis, and management of large volumes of data generated by wearable devices and other IoMT devices. Utilizing cloud computing in the healthcare IoMT sector allows for the effective identification and treatment of illnesses, cost reduction, enhanced outcomes for patients, and increased healthcare quality for healthcare professionals [45].

The performance evaluation of accessing the cloud server in terms of the rate of success in delivering data was considered in [46]. It presented the execution details of proprietary backend server software for an IoMT health monitoring system. Upon identifying vital signs, the system transfers data to a cloud server. The system exhibits remarkable performance and precision compared to current patient monitoring systems, attaining a high success rate for broadcasting IoMT data.

In the same context, the work in [47] addressed the need for precise health status monitoring for COVID-19 patients, particularly those experiencing moderate respiratory distress. The system employs sensors to monitor essential physiological indicators, transfers the collected data to the cloud, which allows for the transmission of sensor data to health professionals for comprehensive analysis, aiding in remote monitoring of patients. The developed system enables remote monitoring of patients, including those with COVID-19, senior citizens, and individuals in remote communities, enhancing their quality of life. The importance of developing remote monitoring strategies for COVID-19 patients, incorporating key indicators like body temperature, heartbeat, respiration, and blood pressure, were highlighted in the paper.

The accuracy of measurement and hence system reliability were experimentally tested in [48]. It presented an effective ECG monitoring system connecting patient to doctors via a cloud server. The IoMT cloud server offers comprehensive data for the diagnosis of heart disorders, enabling remote monitoring, examination, and alerts, minimizing hospital visits. Experimental results demonstrated system reliability, comparing it with current techniques, followed by performance evaluation. The system detected a total of 24 QRS complexes with 100% accuracy, where the QRS complex represents the depolarization of ventricles. The patient's heart rate and RR intervals were analyzed, showing variations in the ECG signal that could be beneficial for diagnosing health problems.

As the access to cloud servers through public communication networks is considered, then the number of users, patients in the case of IoMT, becomes an effective parameter. The work presented in [49] focused on creating a non-intrusive tele-monitoring system for sleep and breathing utilizing remote bio-signal monitoring technologies. The system employs an IoMT bio-signal measuring system, an on-bed sensor system, a web server, a cloud computing server, and a database. Cloud computing allows for the gathering of diverse IoMT sensory signals from many locations using wireless connectivity and facilitates the storage and management of large volumes of data generated by multiple users in distributed computing environments. The developed unobtrusive monitoring system showed comparable performance to FDA-approved sleep trackers in measuring sleep efficiency and respiration rate. The system successfully monitored the physiological status of multiple users without spatiotemporal limitations, achieving data processing times of 0.15 seconds for 10 users and 4.60 seconds for 300 users. It can be used for continuous bio-signal monitoring in personal, public, and clinical settings, aiding in health record creation, disease detection, sleep health management, and circadian rhythm prediction.

C. Communication

Communication technologies like Bluetooth, Wi-Fi, and GSM facilitate data exchange between IoMT sensors and healthcare professionals. Technologies like these enable the creation of a smooth and instantaneous communication network among patients, professionals in healthcare and medical gadgets. Communication technologies are crucial in facilitating the smooth integration of IoMT devices in the healthcare field [45].

The performance of the standard communication protocols used within the IoMT was evaluated in [50]. The study examined the need for a remote patient health monitoring system capable of continually analyzing health data such as body temperature, ECG, heartbeat, and GPS position to identify critical situations and provide prompt medical care. The system employs many hardware components, including an Arduino board, ESP8266 Wi-Fi module, GPS module, AD8232 integrated circuit, and GSM module. The research results showed no loss of packets and no faults in personal and public domain networks, achieved through the MQTT protocol's checksum function. Where the MQTT is a standards-based messaging protocol, it can be considered as a set of rules that manage machine-to-machine communication. The delay jitter in broadcast network performance was almost 10 times higher than in the private network due to the broadcast network's better transmission gap.

Practical tests of different communication technologies to deliver data under real cases were considered in [51]. The study presented a sophisticated IoT system designed to monitor COVID-19 patients from a distance and facilitate the exchange of clinical information among medical personnel. The system combines a portable IoT device with a remote monitoring application to gather clinical parameters and other data for immediate monitoring and statistical analysis. The objective was to limit the potential for contamination and guarantee prompt action for patients. The study aimed to provide a cost-effective, energy-efficient, and advantageous alternative for healthcare. The study discussed the global COVID-19 situation, with 181,521,067 confirmed cases and 3,937,437 deaths reported by the WHO. The paper discussed the use of radio wave-based standards such as Bluetooth, Zigbee, WBAN, and WiFi for medical wireless sensor networks. It highlighted the importance of high-speed WiFi connections for transferring patient data to a remote server.

D. Artificial Intelligence

Artificial intelligence techniques in the healthcare sector use clinical, laboratory, and demographic data to conduct analysis, diagnosis, and prognostic prediction for various diseases [52]. In addition, they provide processed data on patient well-being progress and enable tailored healthcare actions. They also offer real-time information on patient health and facilitate personalized healthcare interventions. There exists a significant degree of excitement about the potential of AI to yield big advancements across several domains of healthcare, including diagnosis and therapy. Numerous studies have provided substantial evidence indicating that AI algorithms exhibit comparable or superior performance to humans in a range of tasks. These tasks include the analysis of medical images and the correlation of symptoms and biomarkers from electronic medical records (EMRs) with the characterization and prognosis of diseases [53]. AI technology can play a crucial role in assisting individuals in maintaining good health via ongoing monitoring and coaching. It can also facilitate earlier detection, customized therapies, and more effective follow-ups [54]. There is a prevailing belief that AI technologies are capable to facilitate and augment human labor, rather than replace the roles of doctors and other healthcare personnel. AI is equipped to aid healthcare personnel with various tasks, such as managing administrative tasks, maintaining clinical records, communicating with patients, and providing specialized support in areas like image analysis, automating medical devices and monitoring patients [54].

Several AI algorithms play significant roles in processing and analyzing data to derive meaningful insights and improve patient care. Some of the main AI algorithms used include:

1) Machine Learning (ML)

ML algorithms are extensively used in IoMT for various tasks such as predictive analytics, anomaly detection, and decision support. Supervised learning algorithms like logistic regression, support vector machines (SVM), and random forests are commonly used for classification tasks, while unsupervised learning algorithms like k-means clustering are used for clustering patient data [55].

2) *Deep Learning (DL)*

Deep learning, a subset of ML, involves neural networks with multiple layers. Convolutional Neural Networks (CNNs) are used for image analysis tasks such as medical imaging diagnostics, while Recurrent Neural Networks (RNNs) and Long Short-Term Memory (LSTM) networks are employed for time-series data analysis, such as monitoring patient vitals over time [42, 56–58].

3) *Natural Language Processing (NLP)*

NLP algorithms are utilized for extracting insights from unstructured clinical notes, medical literature, and patient records. NLP techniques such as named entity recognition (NER), sentiment analysis, and topic modeling help in tasks like clinical documentation, information retrieval, and summarization [57].

4) *Reinforcement Learning (RL)*

RL algorithms are employed for optimizing treatment strategies and resource allocation in IoMT systems. RL agents learn to make sequential decisions by interacting with the environment and receiving feedback in the form of rewards, enabling adaptive and personalized healthcare interventions [42].

5) *Genetic Algorithms (GA)*

Genetic algorithms are evolutionary optimization techniques used for feature selection, parameter tuning, and model optimization in IoMT applications. They mimic the process of natural selection to iteratively search for the optimal solution in a complex search space, improving the performance and robustness of AI models [59].

However, many variants and modifications of these AI algorithms have been employed and evaluated in the literature. The performance of the FusionNet model was evaluated in [59] when it is used for anomaly detection. FusionNet is an ensemble model combining various machine learning algorithms. FusionNet's performance was compared against three traditional models: SVM, K-Nearest Neighbors (KNN), and Random Forest (RF), across two datasets. FusionNet demonstrates exceptional accuracy and precision on both datasets, outperforming traditional models significantly. Its unique architecture, combining Random Forest, K-Nearest Neighbors, Support Vector Machine, and Multi-Layer Perceptron, allows FusionNet to excel in anomaly detection with high accuracy. The study concludes that FusionNet showed superior performance compared to traditional models and held promise for real-world applications in security, healthcare, and other domains where anomaly detection is crucial.

A framework that employs a convolutional neural network with long- and short-term memory (CNN-LSTM) was proposed in [60] to develop a patient activity monitoring system that can accurately recognize human actions. The findings show a notable accuracy rate of 99.53%, exceeding the performance of similar algorithms by a minimum of 4.73%.

A wider scope to IoMT was presented in [61]. The study examined the collaboration of IoT and artificial intelligence for remote healthcare monitoring systems in intelligent cities. The paper emphasized using IoT sensors, AI, and machine learning techniques for data analysis. The research also discusses the use of the Support Vector Machine algorithm to predict health status. The presented analysis shows the expected effectiveness of deploying AI algorithms into different IoMT technologies to improve interoperability and enhance performance.

Cough detection and analysis was considered in [62]. It used IoT and AI to monitor and manage COVID-19 patients. A cough detection deep learning model was created. A pulse oximeter, infrared temperature sensor, and Arduino 33BLE sensing were used in the prototype. The data was stored in Firebase and shown online. The accuracy of the Deep Neural Network (DNN) model for cough detection was 89.47%, and the CNN model for cough detection was 93.1%, which was higher than the DNN model.

Fuzzy logic was used in [63] to analyze patient data. The presented work focused on the task of identifying and dealing with epileptic seizures, which provide difficulty owing to their unexpected occurrence and sometimes harmful bodily manifestations. It proposed a system that integrated an IoT platform with Short Message Service (SMS) technology to provide immediate alerts to medical staff in the event of abnormal situations. The system employed hardware components such as ECG sensors, accelerometers, and body temperature monitoring and utilized a fuzzy logic algorithm to categorize seizures. The prototype of the epileptic monitoring system has achieved an average accuracy of 98.90% for body temperature, 95.49% for heart rate monitoring, 83.0% for muscle spasm, and 87.21% for fall detection.

E. Blockchain

Securing the remote patient monitoring (RPM) system is crucial. Given that vulnerability in such a system has the potential to allow attackers to steal or alter essential data, and put the patient's life at risk. In the context of IoMT, security threats such as unauthorized access, data breaches, malware attacks, device tampering, and supply chain vulnerabilities pose significant risks to patient safety and privacy. Addressing these threats requires robust authentication, encryption, access controls, and regular security assessments to safeguard IoMT devices and data. To mitigate these security threats effectively, IoMT systems require robust mitigation strategies. These strategies include implementing strong authentication mechanisms, such as multi-factor or biometric authentication, to ensure only authorized users access devices and systems. Encrypting data transmission using protocols like SSL/TLS helps safeguard data in transit, preventing unauthorized interception and tampering. Access controls should be enforced to restrict user privileges and limit access to sensitive data based on the principle of least privilege [64]. The blockchain has emerged as a promising technology that can securely store and protect assets via a transparent and decentralized ledger. Within the healthcare industry, where the secure administration of patient data is of utmost importance, blockchain technology has the potential to effectively solve this difficulty by offering a fast, transparent, and tamper-proof system for managing patient healthcare data [65].

In the context of IoMT, several blockchain architectures are employed to address specific requirements and challenges in IoMT applications [64–66].

1) *Permissioned blockchain*

In permissioned blockchain architectures, access to the network and participation in the consensus process are restricted to authorized entities, such as healthcare providers, medical device manufacturers, and regulatory bodies. This approach ensures that only trusted parties can validate transactions and maintain the blockchain ledger, enhancing security and compliance with regulatory requirements.

2) *Consortium blockchain*

Consortium blockchain architectures involve a group of organizations collaborating to operate and maintain a shared blockchain network. Each participant in the consortium maintains a copy of the blockchain ledger and contributes to the consensus process, promoting decentralization while maintaining a level of trust among consortium members. Consortium blockchains are well-suited for IoMT applications involving multiple stakeholders, such as healthcare networks or medical research consortia [59]

3) *Hybrid blockchain*

Hybrid blockchain architectures combine elements of both public and private blockchains, allowing for greater flexibility in IoMT applications. In a hybrid blockchain, certain transactions or data may be stored on a public blockchain for transparency and accessibility, while sensitive or confidential information is stored on a private blockchain with restricted access. This hybrid approach enables IoMT systems to leverage the benefits of both public and private blockchains, balancing privacy and transparency requirements.

4) *Sidechain*

Sidechain architectures involve the creation of parallel blockchain networks that are interoperable with a primary blockchain. In IoMT applications, sidechains can be used to address scalability and performance issues by offloading certain transactions or data processing tasks to separate blockchain networks. Sidechains can also enable the implementation of specific features or functionalities tailored to the requirements of IoMT use cases, such as data provenance tracking or smart contract execution.

5) *Off-chain solutions*

Off-chain solutions complement blockchain architectures by providing additional layers for storing and processing data off the main blockchain. Off-chain solutions, such as state channels or distributed file storage systems, enable IoMT systems to handle large volumes of data or complex computations more efficiently while maintaining the security and integrity of on-chain transactions. Off-chain solutions are particularly useful for IoMT applications requiring real-time data processing or high throughput, such as remote patient monitoring or healthcare analytics.

These blockchain architectures offer diverse approaches to address the unique challenges of managing healthcare data in IoMT systems, providing robust solutions for ensuring data security, privacy, and interoperability. The selection of a specific blockchain architecture depends on factors such as the nature of the IoMT application, regulatory requirements, and the desired level of decentralization and scalability [64, 67, 68].

The primary objective of many works such as [69] was to ensure safe transmission and storage of patient data in IoT-based E-healthcare systems. The primary obstacle was in safeguarding data from both abuse and illegal alterations. The suggested method combines IoT devices with a lightweight block cipher technique. The proposed lightweight ciphering technique for IoT-based e-healthcare systems showed computational efficiency. The encryption time for the proposed technique was comparable to other standard block ciphers. The presented results and analysis show a trade-off between the required level of security and system computational complexity. That is, higher data protection criterion is obtainable at the expense of more complex encryption algorithms and hence longer system response time, and vice versa.

VI. CHALLENGES OF IOMT

It can be confidently stated that the healthcare industry has changed due to the advent of the IoT. Nevertheless, there are persisting obstacles to surmount, such as the issue of data security, which entails safeguarding patient information and data housed on servers. The incorporation of protocols among equipment, such as sensors and external devices, can lead to data collection complications due to the multitude of protocols employed. Thus, it is imperative to guarantee that medical software adheres to Health Insurance Portability and Accountability Act (HIPAA) and Health Information Technology for Economic and Clinical Health (HITECH) regulations to protect data security.

Data overload and precision can also be challenging since the influx of data from several interconnected devices within the same extensive data system may result in a progressive decline in accuracy, causing confusion among medical professionals. Moreover, the cost of IoT technologies is deemed more significant due to their precision and absence of discomfort during therapy. Notwithstanding these obstacles, it is imperative to decrease the costs and render these technologies available to all communities, guaranteeing a safer and more effective healthcare system [70].

Cost reduction of IoMT services was considered in [71]. It discussed the rising prevalence of cardiovascular disease (CVD) patients in Bangladesh and the need for an affordable healthcare system. The proposal suggested using bio-sensors in a microcontroller-based system to enable ongoing monitoring and data collecting. The technology is economically efficient, making it accessible to low-income nations such as Bangladesh. The proposed IoT-based healthcare system successfully monitored CVD patients, costing around $80 to $100, which is affordable for low-income countries like Bangladesh.

However, more challenges encounter the application of IoMT in remote patient monitoring and treatment, including mobility, network lifetime and energy efficiency [72]. The latter are highly related with wearable devices which face technical challenges, notably limited battery life and susceptibility to environmental damage. To extend battery life, strategies like using low-power components, optimizing software, and implementing energy harvesting are crucial. Ensuring durability involves designing devices with water and dust resistance, rugged enclosures, sealed designs, and shock-absorbing features. By addressing these challenges, wearable devices can offer enhanced reliability and performance in various applications [13, 73]. A compromise among system requirements and implementation challenges is a must to achieve reliable operation. In [74], system cost and performance were optimized under practical operation conditions. The presented work used a gradient descent-based algorithm to minimize the overall expenses of leasing bandwidth for remote health monitoring. The algorithm optimizes cost, reliability, delay, and performance, particularly under challenging conditions.

An implementation of the balance between system requirements and performance metrics was in [75]. It introduced the VITAL APP, an IoT-based device for monitoring patients. The device was developed to enhance the accuracy of collecting and measuring vital signs in medical environments and delivering instantaneous information and notifications. The device has been reported to be an acceptable tool in patient monitoring under the practical test conditions. The mean differences and limits of agreement for pulse rate, body temperature, and blood pressure measurements between health professionals and VITAL APP were calculated, showing uniform linear relationships for all vital signs.

Implementing IoMT systems in real-world healthcare settings faces hurdles like integrating with existing infrastructure, user training, data security, maintenance, and addressing costs and ROI concerns. These challenges necessitate interoperability, comprehensive training, robust security measures, proactive maintenance, and demonstrating value to stakeholders. Addressing these challenges collaboratively ensures successful IoMT adoption and enhances patient care [30, 73].

VII. CONCLUSION

The incorporation of IoT technology in healthcare industry has demonstrated its significance in enhancing patient care services. The IoMT has been applied and tested under different operation conditions in the literature. The obtained results and qualifications emphasize the significance of IoMT capabilities and services, including:

- Remote monitoring which enables accurate real-time data collection, facilitating prompt actions and enhancing patient well-being.
- Reducing healthcare expenses by optimizing procedures, automating routine tasks, and preventing expensive interventions.
- IoMT allows optimizing resource utilization and IoT technologies to enhance the healthcare system’s efficiency, responsiveness, and cost-effectiveness, benefiting healthcare providers and patients.
- Accurate enough and cost effective IoMT setups and solutions are possible for application in non-wealthy countries to provide an efficient and reliable remote healthcare tool.

However, these advantages are not for free. Practically, there are many challenges that may restrict the quality of service provided by IoMT systems, and impose trade-offs on system design. The most prominent challenges include:

- Maintaining data security through protocols and algorithms whose required performance is achieved at the expense of added overall system complexity and latency.
- Energy efficient and cost effective IoMT solutions may not always be achievable.
- Interoperability issues arising when diverse IoMT devices and platforms are to be connected together.
- Developing scalable and flexible architectures and platforms capable of accommodating IoMT expansion.

These challenges open wide scopes for many research directions to address the challenges and improve system performance under various operational conditions. Possible future research trends may be expected in the following directions:

- Improving the characteristics of biosensors and enhancing the performance of communications and cloud computing infrastructure, can better facilitate more reliable, accurate, energy efficient and/or cost effective IoMT setups.
- Developing new IoMT architectures that can be more efficiently scalable and compatible with different platforms.
- Getting benefit from recently developed AI tools and embedding them into different components of IoMT based healthcare systems to improve data analysis capabilities, insights extraction, diagnosis, treatment scheduling …etc., in order to improve healthcare outcomes.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

The paper conceptualization, material collection and filtering have been done by Lamees S. Ahmed. The supervision, validation, methodology and editing review have been done by Abdulrahman I. Siddiq. Literature analysis, presentation, paper organization and the approval of the final version have been done by both authors.

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