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Internet of Medical Things (Iomt) in Clinical Instrumentation: Design, Integration, and Applications

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Annotation: The foundation of medical IoT devices is the daily circumstances, technological advancements in the Internet of Things, artificial intelligence-based machine learning technology, and the demand for more advanced health care. Thus, IoMT activities revolve around gathering and processing patient data to support better health management and control, e.g. wearable devices to collect health data, send them to a cloud-based platform for communication, processing, an online interface for healthcare professionals to analyze and visualize the information. Recently, demand for a more advanced health care system, i.e. massive health data collection, advanced processing systems producing preventive alerts and offers for patients, have raised new research questions surrounding this technology.

The motivation to better respond to these aspects lies in the complexity of the IoMT environments, which enables the presence of a huge number of devices, connections, and interactions, on a geographical scale that is often unknown or not controllable, e.g. by health care professionals, exposing to communication and processing that are often performed by unknown actors over unknown networks and geographically dispersed data storing, all in a context sensitive to human well-being .

Given the increasing number of personal health monitoring devices connected to IoMT infrastructure and adding the energy constraint, as some devices cannot be plugged continuously to a power supply, experts and researchers are facing emergent problems, involving hardware and software debugging, pollution of medical data with excessive alerts (alarms) and missing diagnoses alerts by important events. Strategies for conducting continuous data reception and synchronization, as well as real-time alert/failure checking and feedback provision, are elaborated. At last, open issues and future research direction on medical IoT operations are discussed.

1. Introduction to IoMT

The Internet of Medical Things (IoMT), as a sub-domain of the Internet of Things (IoT), is a combination of medical sensors and devices connected through the network that collects data from patients, analyses it, and provides suitable medications and suggestions to them. The Medical Internet of Things (IoMT) consists of billions of medical sensors/devices or gadgets that are connected to wired or wireless networks to work together as an IoT system. IoT-based applications in the healthcare sector have huge future scopes. Products and services provided by the healthcare sector facilitate the enhance healthcare, decrease pressure or workloads on physicians or nurses, and assist patients to receive treatment outside the hospital or at home. The framework of the IoMT applications provides ease to combine the benefits of cloud computing with IoT technology to the medical industry. The network structure and the methods of transmitting patient information received by various sensors and medical devices generating numerous types of data to a medical service providing network are defined in the framework. The topology of an IoMT is built with various IoT medical system/network components logically coupled in a medical context. Various types of sensors are used in the IoMT healthcare application like blood pressure monitor, thermometer, endoscopy monitor, pulse oximeter, EEG, ECG and EMG, etc. to read patient medical conditions [1]. The IoMT has been improved for the examination and treatment of numerous medical disorders because it captures a variety of medical data that contain states of patients' health. In this regard, Computer-aided IOMT-based approaches to disease detection, and diagnostic test acquisition have been discussed concerning some medical disorders like cardiac disorder, thyroid abnormalities, breast cancer, etc. in recent decades. The most common neurological disorder, dementia, and IoMT-aided initial detection and monitoring of its symptoms and conditions have been summarized. The IoMT has already yielded impressive results in modern medical practices, and the next step is to develop a software model with a comprehensive roadmap to be used by practitioners and software developers [2].

2. Historical Context of Medical Devices

The development of modern medical devices depends on a number of key technologies, including miniaturised and affordable electronics, MEMS sensors, and wireless communications. These technologies were matured and refined to create modern medical device applications. The past few decades have also driven a technological push towards smaller size devices with less invasive procedures, coupled to telemedicine and telehealth systems approach of modern healthcare. The proliferation of these technologies has also created the opportunity for a greater diversity of devices and systems. In 1870's and in the following decades, audiometers, sphygmomanometers, picture tubes, amplifiers, teletherapy machine, heart valve prosthesis and many other medical devices were invented and put into clinical practice. Acoustic and pneumatic devices for the detection of heart sounds, sphygmomanometer for blood pressure measurement, and other devices slowly gained acceptance and became a routine part of examination in the early decades of the 20th century [1]. By 1910's further well-differentiated instruments became available such as ventilators, heart-lung machines, electrophysiological devices for electroencephalogram and electrocardiogram record. A new generation of large medical devices was introduced in 1940's and 1950's based on the introduction of the new technology such as X-rays and high-energy radiation or to measure the physical properties of body constituents. In the same era and the following decades, numerous devices became available or were commercialised for pharmacodynamics and biochemical analysis purposes or physiological assessment. During this period, devices for imaging and inspecting the morphology of the organs and tissues of the body were introduced. In recent decades a great variety of new and more advanced devices were conceptualised and introduced such as tomosynthesis, functional MRI, cryoablation, etc.

3. Fundamentals of Clinical Instrumentation

Clinical instrumentation is an important part of the Internet of Medical Things (IoMT). An IoMT medical apparatus reads data from a patient using different sensors and medical devices. The signals collected contain a lot of valuable physiological and environmental information about the patient that is exploited to determine patient characteristics and impending illnesses. The data is delivered to a healthcare platform via the Internet, where it is aggregated and cleaned using standard techniques. After persistent storage of the data in the cloud, data are processed in real-time using big data technologies including Apache Spark, and then periodic or event-based alerts are sent to the caregiver's smart device to assist with timely medication administration and troubleshooting recommendations. The Internet of Medical Things (IoMT) is a difficult amalgamation of bio-sensors or medical devices, a network to integrate the devices to the Internet, data analytics technology, and many services to provide analysis-based insights. The design, integration, and implementation of these components in the healthcare domain are elaborate. Bio-sensors or medical devices read temperature, heart rate, ECG, EEG, glucose, and a range of other information from patients. These sensors convert the signals to a digital form, which is then sent to a Data Aggregation Center (DAC) over a cellular radio, WiFi, or other available protocols under different topologies. The significance of the integration and data analysis techniques of the various components is demonstrated. The entire system is robustly designed to be fault-tolerant, scalable, and capable of handling a variety of medical devices and a large amount of data. An advance in clinical instrumentation, in which all sorts of instruments can be made to read data from an advanced digital machine. The acquired signals are carefully processed and analyzed at different levels to make actionable insights [2].

4. Architecture of IoMT Systems

IoMT is generally referred as an IoT healthcare system, which enables real time monitoring of patient's health parameters by healthcare providers remotely. IoMT consists of smart IoMT enabled devices, which can be used to monitor one or more health parameters, like BP, heart rate, temperature and so on. A gateway collects this health data of a patient and then it is transferred to the cloud for further analysis and storage. The healthcare providers can access required details of the patients using their smart devices. If the patient requires immediate medical attention, the healthcare providers can alert the ambulance service. An IoMT architecture has been proposed in which microcontroller based IoMT devices are deployed with real time embedded software programmed into it. For establishing the communication among these IoMT devices proper communication protocols are required. These devices are directly connected using Wi-Fi or Bluetooth and remotely connected using a gateway [2]. A master-slave protocol has been used to collect health data from the deployed IoMT devices. Once the gateway receives this health data, it forwards the data to the cloud infrastructure using MQTT protocol. This architecture supports real time transmission and reception of health data of patients.

This paper proposed an architecture model for wearable and portable, low power and low cost medical sensors/devices, which could help in increasing the deployment of wireless sensors in health monitoring applications. Representing a general architecture for wireless sensor health monitoring applications. Sensors may be used as a modular health analysis system for bio-signals monitoring with pre-processing disabled for all unconnected signals, controlled through a wireless network, which allows an integration into the present telemedicine infrastructures of hospitals. Power-saving alternatives allow continuous measurements without the major disadvantage of a wired connection. Application scenarios for a modular low-power tele-health monitoring device with programmable digitization, wireless communication, and low-power peripherals are shown in this document. [3][4][5]

5. Design Principles for IoMT Devices

Based on the principles of the Internet of Things, the Cloud-Raspberry Pi wireless network integrates a variety of sensors, modules, IoT devices, software, databases, and resources to send medical information from wearable sensors and apparatuses to the cloud using RPI and IoT technology. The cloud database facilitates coordination, retrieval, and display of retrospective analyses, while the android with M-Bluetooth executes tasks like the patient over the cloud on the UI.

In the latest era, patients can be monitored via portable multi-parameter monitoring systems before arriving at the emergency unit. The cloud-based patient carries the chance to report instantly on health status and draw the required assistance to quench the exigency. An IoT controller with RPI can observe diverse medical sensors to trace heart beat, body temperature, and electrocardiogram, and dispatch commands coded on Apache Web Server over SSID networks through a locally-constructed network [1].

Implementing, deployment, and evaluation of IoMT healthcare monitoring systems relies on key design principles, with Consideration of the Patients, the Context, and Information Processing principles in design processes. The designer’s understanding about patients is essential to envision a feasible, acceptable healthcare monitoring system. The location where the system is to be deployed end product qualities and the environmental parameters where IoMT health monitoring systems function need to be specified.

Information processing of healthcare system’s input data produces a result that can accommodate patient feedback and analysis requirements. The monitoring systems pre-process patient data with signal processing methodology for noise and artifact extraction before parameter calculation. Acknowledge on patient cognition, feedback task, UI, interpretation, and trust is needed to extract and relay result. With decision support systems proposed for prevention scheme realization, alerts need to be timely and non-intrusive. Alongside security, privacy, and confidentiality signify huge importance in any health monitoring systems. [6][7][8]

5.1. User-Centric Design

The user-centered design emphasizes humanities and social studies, along with mathematics and computer science, in adding value to medical devices. Providing smart, safe, and secure devices in complex clinical environments requires a context-aware human-centered design process. For such a design approach, a case study of a Remote Cardiac Monitor (RCM) is discussed. The study investigated how to design a user-centered, smart, safe, and secure medical device for the everyday use of patients. Service functions and complexities proposed by designers were thoroughly analyzed based on the context of use (COU). COUs of patients tended to develop autonomously in the operational contexts of smart devices, application-based services, multimedia data logging, and individual monitoring devices. On the contrary, patients were worried about inability to use services and side effects caused by incorrect usages in the context of safety, security, and unintended systems. All concerns reported by patients should be put in the process of user-centered design methods in advance of developing new technologies [9].

User-centered design requirements for the safe and secure enhancement of RCM services were suggested to new providers. In addition, co-design methods for contexts of the daily life of patients and connected operational processes of medical devices were proposed to develop a safe and secure experience that would be largely differed from conventional methods social studies and humanities. The methodology can be applied to any type of medical devices, and the users to be engaged are patients, medical professionals, and personnel of other institutions beyond the paradigm of biomedicine [10].

In providing smooth parsing experiences, medical device manufacturers have concentrated on appropriate user-centered designs to develop user-friendly devices, and medical professionals have paid attention to safety and security measures against inappropriate usages. However, challenged with rapidly evolving Internet of Things (IoT), a medical device user-centric design considering clinically complex environments is required to provide "smart medical devices."

5.2. Safety and Compliance Standards

The medical industry has seen a surge in interest in the Internet of Things (IoT) applications due to Bluetooth, RFID, and smartphone expansion. The Medical Internet of Things (IoMT) is regarded as a subset of IoT, where sensors and other networking devices collect patient information both inside and outside the hospital. Transmissions are either wireless or wired, and the medical service providers are cloud-computing-based integrated agents that examine and visualize patient information in real time. As one of the key components, the design of medical sensors in an IoMT ecosystem determines the type and frequency of data acquisition, whether invasive or noninvasive, implantable or stand-alone, and its size and power source based on the application. This review details the custom design of the instruments in an IoMT system structure, from the sensor-level hardware design to the system-level integration with case studies. To the best of knowledge, this is the first review that covers the IoMT instrumentation appropriately [1].

IoMT has evolved very quickly in therapeutic devices, diagnostic devices, monitoring devices, and other different categories of devices. In case of the therapeutic IoMT, it can be categorised as small-scale drug injectors, drug disposal devices, implant-based devices, medication adherence smart pillbox, dental devices, radiation delivery devices, insulin-drug delivery devices, surgical instruments, prosthetics, bio-scaffold for tissue regeneration, AI-based smart inhalers, etc. In case of monitoring IoMT, lead section of wearable devices, cardiac monitoring, vitals monitoring, activity tracking, newborn baby care, denture care, epilepsy monitoring, elderly emergency detectors, etc. are there. Diagnostic IoMT includes real-time test results, gene sequencing, respiratory tract infection detection, colourimetric diagnostics, smart capsule endoscopes, etc. Ultrasound devices, vagus nerve stimulators, and expensive support ventilators are used in a hospital's ED or ICU or hospital wards are the costly and non-portable devices that come under clinical edges. [11][12][13]

6. Integration of IoMT in Healthcare Systems

The Internet of Medical Things (IoMT) is a term used to refer to the remarkable number of sensors and diverse medical devices that are currently at play in gradually collecting data from patients and then assessing and providing suitable medications and suggestions to the patient. The Medical Internet of Things (IoMT) refers to the existing portion of the Internet of Things, which offers enormous potential for the healthcare sector. There are many aspects of this sector’s products/services that advance/impact healthcare, eg., ease a portion of the burden on doctors and nurses; self-continuation of the patient at outside/at home instead of hospitals or healthcare facilities, etc. The IoMT application’s framework makes it easier to combine the benefits of cloud computing and IoT technology with the medical industry and define the methods of transmitting patient/personal health information from a number of different sensors and medical devices to a particular medical service-providing network [1].

The configuration of various IoT medical system/network components that are logically coupled in a medical context is referred to as the topology of an IoMT. This topology utilises a number of sensors, eg., sphygmomanometer, thermometer, endoscope monitor, pulse oximeter, EEG, ECG, EMG, etc., in a suitable combination to continuously read a patient’s conditions at any given time, taking into account their prior state, prescribed medications, etc. Based on the acquired information and a preset rule, each device then assesses that state and provides medication/advice to the patient accordingly. The measured glucose information in the blood of a human, edges in the complexity of the world is achieving on-device learning for ML algorithms on the medical devices themselves. The device has designs and tests a complete and capable soft/flexible electrochemical ion-induced transport to capture the on-chip glucose test sensing as a soft gel bioreactor [2].

6.1. Interoperability Challenges

The Internet of Medical Things (IoMT) represents a revolution in precision health that emphasizes how technology can actively facilitate and promote healthy behaviors. IOHT, a subclass of IoT, emphasizes the development of smart, connected healthcare systems for people, organizations, and things. While industry and academia have made significant strides toward developing IoT solutions in healthcare, challenges and opportunities remain, especially regarding interoperability, ethics, cybersecurity, and health equity. Interoperability challenges affect the integration of new IoMT technologies into existing healthcare systems. Interoperability refers to the integration of disparate health information systems, devices, and applications. Existing standards like [14] are being actively incorporated into the aforementioned efforts. However, their adoption remains in the scientific literature and commercial standards-proposal trade publications. Further, existing standards were developed for institutional (or enterprise) systems and are ill-equipped for the new data logic, distribution, and other requirements of IoMT-based infrastructures. New, more versatile negotiation and application-layer protocols are urgently needed. Most fundamentally, this discussion presumes that “good” technologies will work their way into practice based on their own merits and benefits. As such, these information channels are naturally advantageous, promoting efficient health delivery and generating comprehensive and computable information to improve care. Communication technologies with these properties have become an important part of the health environments of wealthy societies. However, there are at least two reasons to be skeptical of this presumption. First, while for computers as a technology this argument holds, it does not hold for electronic health record [10]. Second, many systemic and behavioral issues arise between the development of a technology and its large-scale, sustained public adoption.

6.2. Data Management Solutions

The IoMT provides implementation support of complex AI algorithms at live data streams, such as video feeds from IoMT devices, and for model training AI tools. The IoMT ecosystem collects, stores, and handles patient data in real time. It consists of data source devices, such as monitoring devices and video analytics; a cloud platform for storage, acceleration, and scalability of the database; and a business entity handling the management and operation of the services and data management. Clinical signal processing and big-data AI tools are used to analyze existing signaled streaming data. Artificial neural networks and a speaker-specific approach are used to augment database construction. Most work focuses on the detection of abnormal breathing patterns and parameter extraction from breathing sounds recorded in a quiet environment and from nondiseased individuals only, while accretive data cases are rare. Safe fast channel access restores outgoing encodings and aids in the decryption of odd-audio with unknown user key packets.

The IoMT is a rapidly growing area of technology and research that offers many opportunities for delivering innovative and smart remote medical services. Security and privacy issues in the IoMT are considered due to the fact that IoMT devices such as sensors, kiosks, and medical imaging systems are vulnerable to security risks. The cloud and fog computing processing additives eliminate the limitations of IoMT devices and latent vulnerabilities. An overview of the opportunities presented by the evolution of advanced cloud and fog computing technologies to improve remote medical services. The impact of cloud and fog computing on various domains of IoMT services, and the opportunities for improving quality, flexibility, accuracy, and safety of the services is covered. The hardware and software components are explained, and the current approaches are reviewed. The challenges faced and research gaps are outlined.

IoMT is the collection of connected goods and technologies used to collect and transmit information regarding patients, treatment, quality of care, processes, and other aspects of care and treatment in a very wide range of medical fields. IoMT is a combination of two existing systems, namely “IoT” and “MT”. The Internet of Things (IoT) is a system of physical devices that helps connect and exchange data over the internet. It has a wide range of applications in various fields such as agriculture, industrial automation, smart cities, transportation, intelligent residential systems, and many more. The IoMT system provides real-time monitoring of patients and helps in chronic disease management to patients, which otherwise would have been impossible with conventional systems. [15][16][17]

7. Wireless Communication Technologies

This paper introduces readers to the concept of the Internet of Medical Things (IoMT) using portable devices, medical software, large data, and cloud computing. In this regard, it will provide research works and innovations as well. With the development of the IoMT, numerous subscribers can be added for personal healthcare monitoring. However, security and privacy concerns may arise as a result. For instance, administering drug doses with insufficient data may result in harm and death. Therefore, providing a domain of intelligent health professionals is substantial. The paper deduces challenges, emerging issues, and a comprehensive study on the IoMT in the area of clinical instrumentation. Presenting IoMT examples, this paper extensively covers the development and innovation of these medical devices introduced in the health institution gradually [1]. The Internet of Medical Things (IoMT) leverages different sensors to observe patient health-related data as well as medical gadgets to treat people. The collected data are then privately evaluated and after analysis, the most suitable medication and suggestions are provided to the patient by healthcare professionals. Through such devices, health professionals are always integrated in a secured manner. IoMT, a subset of the Internet of Things (IoT), is composed of numerous health gadgets that are used in the medical category designed for its own kind of purposes. This type of IoT has a large potentiality in the field of healthcare. Products and services from this area provide a new perspective on healthcare. With the help of these devices, doctors, and nurses are relieved from plenty of burden. Patient convenience is provided with healthcare facilities outside of a hospital or in their own home. Proper understanding of this architecture makes the worldwide winning case in dollars through the combination of cloud computing benefits with IoT technology in the medical field. Besides, ways are described of how to transmit the collected patient data from various sensors and medical devices to a particular medical service providing network.

7.1. Bluetooth and Wi-Fi Applications

Bluetooth Low Energy (BLE) technology was proposed for health information measurement systems. A system was designed consisting of two circuit subsystems: a BLE switch control and a BLE control board. The switch control circuit connected to the different sensors. The control board operated on user-defined sensors' settings. Health activity measurements were periodically sent via BLE. The system was characterized based on various health activity measurement applications. The BLE system was additionally connected to a mobile application, which collected, displayed, recorded, and processed the health data. Subsequently, the health activity recording was uploaded to a server in real-time for long-term monitoring [1]. The IoT model achieved a significant recording of the health activity, showing sufficient accuracy for heart rate and stride length measurement applications.

A novel method of medical nursing was designed under the Medical IoT by developing an IoT network based on Wi-Fi and RFID technologies. The application environment included Wi-Fi signal coverage in the ward and network access to the hospital LAN. The design addressed three main aspects of the work: the design of the sphygmomanometer terminal, the design of the nurse workstation application software, and the FPGA design [18]. The access control provides data integrity and confidentiality. The data flow includes patient data acquisition, data transmission, data storage, and data monitoring. RFID-based information transmission includes a mobile RFID reader. Accurate temperature monitoring is achieved without affecting normal monitoring with a small circuit on PCB. The innovative wireless monitoring technology leads to real-time, automatic, and remote control of an important nursing stage, ensuring the safety of the monitoring instrument. On the basis of the existing LAN, the patient is provided with a standard Wi-Fi connection, ensuring the availability of information to assist the decision for further treatment. The overall IoT system provides a comprehensive PDA for safety monitoring of critical patients in real-time.

7.2. 5G and Future Trends

The modern era of healthcare evolution in the 5G domain: The standard for longer-range, lower-power, and highly adaptive internet connectivity with the Fourth Industrial Revolution (4IR) was introduced with the integration of the Internet of Things (IoT) along with artificial intelligence (AI). IoT is a major enabler of 5G. A combination of multiple IoT technologies improves asset dependability and productivity while lowering operating costs. As cloud intelligence and provision is receiving attention, the occurrence of low-powered long-range (LoRa) connections has gained much consideration regarding long-range wireless communication for IoT architecture. 5G is a worldwide collection of telecommunications standards, and the 5G Alliance has initiated multiple worldwide academic, research, and development activities since 2009. Healthcare delivery has entered the IoT era, and much advanced and customized medical care provision technology is under development. Wafer-level integration of multiple functionalities on a single chip IC (integrated circuit) for medical diagnosis has entered production of the 50–100 μm level, and it is acceptable for high throughput. A convenient position of medical IoT devices of size ≤ 200 μm was implemented on silicon wafers. Tiny wireless connection technologies such as BLUETOOTH Low Energy (BLE) and long-range awaken-able connection & synchronous transmission (LACST), ultra-high-frequency (UHF) radio frequency identification (RFID) has been invented concerning daily discrete items. UHF-Implantable medical chip (IMC) device-bio-compatible IC design, system integration and sensor interface design are allocated. These LOHC IMCs can be advanced for individual unrestricted distributed medical monitoring, which can be integrated into the influencers for unlimited medical support of diseases.

Human beings and mobile technologies have become prominent in most aspects of daily life. The rapid advancement in digital connections, networks, and devices has assisted in smart, prefabricated, and diversified globalization. In the electronic segment, the IoT ecosystem has led to the industrial internet, smart homes, and connected infrastructures, enhancing the safety, efficacy, and comfort of food, energy, life, and dwellings. Connectivity using wireless devices such as smartphones, smartwatches, fitness bands, wearables, etc. can monitor health and lifestyle. Growing awareness of health monitoring using mobile technology has driven the consumer healthcare instrument market. Globally, there will be approximately 20 billion devices, out of which ‘healthcare’ will be around 2.3 billion devices. The smartphone-o-stethoscope with built-in virtual disease diagnosis apps, artificial-intelligence-enabled glucose meter, and connected dermatoscope with auto-analysis and remote consultation are integrated prototypes as home-use segmented devices [1]. Personal diagnostic devices are rapidly advancing with more ICU-like medical testing capabilities. In recent years, the health monitoring device segment has accelerated due to the COVID-19 pandemic query sensation. Focus on health/personal care and design technology compatible with user needs is driving growth in mobile health (mHEALTH) and tele-health systems.

8. Data Security and Privacy in IoMT

In the past years, with the exponentially growing use of IoT devices in healthcare, common industry concerns have arisen. Such concerns encompass privacy and security, compliance, connectivity and coverage, and implementation and deployment. Compliance to standards, policy, and federal regulations is difficult when there is no industry standardization. Increased connectivity creates the potential for more points of failure and attack vectors. From a deployment perspective, network configuration, device management, and vulnerability handling become complex tasks, as a single deployment can include equipment from dozens of vendors. Even with early commercially available IoMT devices, such challenges are apparent. Data leaks in implantable devices and the hacking of diagnostic and therapeutic devices have been reported.

Security of medical data and IoMT devices has gained prominence in recent years due to widespread deployment in healthcare settings. Infection and exploitation of computers has risen, leading to interception of patient data, denial of service attacks, and coercion to shut down impacted devices or release patient or hospital information. High-profile ransom attacks have targeted small private practices, regional hospitals, and large multi-facility hospitals, often crippling their networks, causing delays in clinical procedures, and raising concerns regarding loss of life, with attackers demanding large sums of money. Competition and collusion among these groups has driven up the cost of attacks for health systems. Malware and ransom attacks have advanced in sophistication and complexity, risking exposure of sensitive health information and resultant financial and regulatory challenges to large health systems.

Regulation of privacy and security concerns in IoMT systems is still evolving. The growing number of devices and the accompanying data collection has caused concern among regulators. This has led to the formulation of rules regarding data ownership, data aggregation and resale by aggregators and cloud companies, concerns of bias and discriminatory practices, and regulation of use by third-party developers and governments. Additions to existing law, such as oversight of IoMT manufacturers, third-party providers, and data resellers may be inevitable. Strategies to minimize exposure to privacy and security threats include regulatory strategies, privacy-by-design strategies, and transparency strategies. [19][20][21]

8.1. Encryption Techniques

The recent explosion in advancement of wireless broadband technology has made life easier for everyone, thus it has tremendous impact on every sector from telecommunication to agriculture. Automation of industrial operations has resulted in tremendous improvement in efficiency, precision, consumption of power, cost control and a total control over production process. In such regards, advancement of networking techniques have resulted in new communication protocol called Internet of Things which has introduced devices equipped with low power/high performance System on Chip to the wireless network to continuously collect, monitor and evaluate the information processed on the embedded hardware device also termed as nodes. As it improves the quality of life, so does the health and well-being of everyone. With the advent of the era of Internet of Things, it has also been envisaged that the devices in Medical systems should also be interconnected to be smarter to promote a more efficient and lightened down health care services. The combination of medical systems and infrastructure with IoT is termed as Internet of Medical Things and focusing the role of IoMT in clinical instrumentation. With jam-packed access in healthcare data with the advent of Internet of Things, Internet of Medical Things networks have also been formed. These IoMT networks devote in monitoring patients suffering from chronic diseases. These IoMT networks are very reliable and dependable because the subsequent actions depend on the ultimately collected patient data.

Network connectivity of medical devices takes care of a subset of IoT technologies termed as IoMT or mHealth devices. Healthcare Systems have been witnessing an accelerating adoption of portable, cost effective and wirelessly connected devices, hence it has been enthused that a number of personal health monitoring solutions constrained by sensors and elaborate wireless communication will emerge in the future. Data encryption schemes focus on low-power, low-complexity ciphering operations suitable for constrained devices and the envisaged lightweight encryption schemes turned its focus mainly on the low-complexity aspects of security primitives. The vulnerabilities of conventional cryptography procedures, and how hardware trojans, side channel attacks, differential fault analysis and reverse engineering tampering techniques undermine the robustness of cryptography. Examples of template based attacks and machine-learning based attacks which compromise cryptographic key personalisation using side channel data thus exposing the whole hospital network for arbitrary patient manipulation. [22][11][23]

8.2. Regulatory Compliance

A regulatory framework must be developed to guarantee the safety of hardware and software systems for distant patient monitoring via the IoMT in order to enable safe and better systems guiding clinical action and hospital intervention from a distance. The global regulatory affairs landscape is currently highly chaotic. Health technology companies are working to produce technologies that can—and frequently do—grow to be larger than regulatory capabilities. The extent of guidance available to the IoMT crowd varies significantly depending on the sort of system being created. Market access for IoT connected devices is carefully controlled, with current regulations stipulating a long approval process prior to entering the market. Unfortunately, over-regulation could prevent health technologies from transitioning to a more patient-centered, preventive mode of operation that is more cost-effective. The Internet and mobile systems must not only support the ideas above, but also create systems that can still cope with risk, fraud, invasion of privacy, and other problems. Despite being excellent for the patient, home monitoring systems for chronic conditions do put new stress on healthcare systems. Such restrictions on efficacy, safety, and costs can slow down development. Profitable health technologies can be developed for wealthy western countries, while medical remote care systems can only be used in the developing world because of the portability of telemedicine. Frequently, no classification schemes or guidance are presented, such that the type of monitoring systems and the nature of the system design either do not fit into the aforementioned or into the more global classification scheme. This void offers space for decreasing boundaries between information and health technologies, providing opportunities for innovative systems and procedures for a greater address of preventive and preemptive health care. Even for currently market-proven preventive technologies, current regulations leave too much flexibility for loopholes and endanger patient safety. The current health technology landscape of the IoMT has gained a great deal of interest and priority that has resulted in an explosion of start-up companies and academic research on units, networks, and the accessibility of Internet-connected health-record systems. A better-established picture of the impact of intended developing technologies is developing in an open interaction between the health care and regulatory affairs communities. However, the substantially changed design space regarding the considered monitoring systems as compared to the current generation of applications is generally recognized. [24][25]

9. Clinical Applications of IoMT

IoMT is a specialized extended arm of IoT that includes all the interconnected devices used to provide timely support to the patient and healthcare industry. Devices can be connected via wired or wireless media, where the former uses telephone wires, coaxial cables, optical fibers, and more. The latter uses various electromagnetic spectrum bands. Today, a significant paradigm shift lies in telecommunication, especially in wireless communications, where medical gadgets can be connected to networks without physically linking each other. Medical sensors, vehicles, portable phones, and security systems are some examples of the wireless world that has become prevailing, which has led to a reduction in wired connection costs and enhanced mobility. Data from these hand-held medical gadgets are broadcasted to networks/servers from where the data are processed and then made available to relevant stakeholders such as doctors, relatives, and patients through technical wisdom and disclosure. Accordingly, big data analytics tools are employed to process the storage requirement of the server, whereas cloud computing techniques are used for the management of IoMT big data. Many researchers are working on improving healthcare infrastructure managed by IoT to improve the quality of life. For instance, a smart hospital system based on IoT that used wireless sensor networks and mobiles connected using the rest architecture. This system has the capability to collect data of patients in a real-time environment. The data is transmitted to a central repository where users can access them using a monitoring app. Likewise, but being more exhaustive in terms of hospital and patient particulars, a variety of potential IoT-based healthcare architectures to support transmission, reception, and processing of medical data. Those models are hybrid with a combination of many other protocols. Different types of medical sensors have also been used to sense the patients' situation. A wavelet transform technique, combined with a multi-class support vector machine, was utilized for the detection of seizures in rats when subjected to the test drug. The performance assessment was performed on three different parameters: accuracy, sensitivity, and precision, each of which was presented separately in a table format. Moreover, how IoMT is useful for child care and elderly care is also explored. To monitor the baby's activities and sleep quality at home, wearable activity trackers and many other devices are invented. An IoT-based healthcare model applicable for both normal OPD and emergency medical conditions. They also highlighted various sensors and wearable gadgets used to monitor patients' health by checking routine parameters like BP, glucose level, and so on. The collected data are forwarded to cloud servers where they are stored. Doctors can access the stored reports using monitoring applications so that corrective measures can be taken on time. Tracking location and accidents with the help of IoT is also presented. It is further argued that, to avoid accidents concerning drivers falling asleep in sleep deprivation conditions, a facial recognition system is implemented. The base station collects this data and warns the driver against dangers/accidents using a steering wheel alarm. Cloud computing is the infrastructure used for the storage and management of IoMT data with ease. An IoT-based home care system for the elderly who are unable to perform daily routine activities due to poor health conditions or loss of memory. This monitoring system takes help from many action detection sensors, wearable body temperature devices, and fixed cameras. The captured data are processed and presented on a graphical user interface that runs on a smartphone or a computer [2].

9.1. Remote Patient Monitoring

Remote Patient Monitoring systems address both clinical and commercial opportunities in the consumer healthcare market. These systems provide specialized services such as remote examination, real-time surgical monitoring, vital sign recording, drug administration, and patient training for chronic diseases, among others. The Internet of Medical Things plays a vital role in these applications. It is expected to innovate modern healthcare by assisting patients through hardware devices and patients' needs and real-time health conditions through software services. IoMT has been a major contributor to telehealth services during COVID-19 times.

A functional design of a miniature portable universal Remote Patient Monitoring system is proposed. The system can effectively measure the static and dynamic states of a patient on a specific part of the body under any external environment. The system also allows patients to consult with physicians remotely and offers a portable ECG vital sign wearable device that can be controlled by a smartphone. A smartphone app can be developed to access the vital sign monitoring server via wireless communication and display real-time graphs and waveforms of four constituent vital signs. A wearable gadget for smartphone systems allows patients to become more independent and self-educated about their health needs. Patients can record heart beats patterns, oxygen levels, pulse response speed, and temperatures of any unknown source for consultation with medical staff remotely via transmission of signal fingerprints and waveforms of each vital sign. Currently, researchers pursue greater convenience and efficacy in healthcare.

An important function in the future healthcare system involves measuring a patient’s vital signs, transmitting the measured vital signs to a smart device or a management server, analyzing it in real-time, and informing the patient or medical staff. Internet of Medical Things incorporates information technology into patient monitoring device and is developing traditional measurement devices into healthcare information systems. In the study, a portable ubiquitous-Vital system is developed and consists of a Vital Block, a small patient monitoring device, and Vital Sign Server, which stores and manages measured vital signs. Vital Blocks collect a patient’s electrocardiogram, blood oxygen saturation, non-invasive blood pressure, body temperature in real-time, and the collected vital signs are transmitted to a Vital Sign Server via wireless protocols. Additionally, an efficient R-point detection algorithm was proposed for real-time processing and long-term ECG analysis. Experiments demonstrated the effectiveness of measurement, transmission, and analysis of vital signs in the proposed portable u-Vital system.

9.2. Smart Wearables

More than one third of adults aged 65 and older fall each year. One of the most frequent reasons for a hospitalization is a fall-related injury. The most frequent health outcome resulting from a fall is a bruise, but more serious injuries include bone fractures and brain injuries too. Being aware of treatment services is vital to receive care following a fall. Information about treatment services is often not readily accessible to users of fall detection devices. The lack of access to treatment services is an important problem, as it leads to poor health outcomes in users of wearable health monitors. Using patient models, a device model, and context information, several treatment services can be recommended to a wearer surrounding the fall incident. As a result, using WIoT provides a recommendation of treatment services in case of a fall incident detected by the device. [26] describe the design of a Smart Clothes System (SCS) platform and the new knowledge of treating a wide variety of health conditions. The SCS platform comprises sensor-equipped clothing, efficient data-processing nodes, and UI interfaces to display output nicely. This chapter also discusses how smart clothing can help in health wellness considering some application scenarios based on the Smart Clothing research and development experience. The technologies in data acquisition and processing, creativity in display user interface and providing a user-friendly experience meeting consumer needs will intensively develop and spread in the domains on consumer electronics and health monitoring. With steadily enhancing performance, the smart clothing platform will become more affordable and applicable for widespread health wellness promotion. Tailored rehabilitation fails to maintain patient motivation in rehab exercises, while remote passive monitoring in smart environments raises patient privacy concerns. [27] proposes a novel open world AI system that combines off-the-shelf wearable sensors and ecological inputs from surrounding environments and social networks to automatically detect changes in the patient’s normal health status. The idea is to extend wearable health monitoring to “digital twin” solutions for swifter seamless online and proactive care. Since the emergence of wearable low power health sensors, monitoring human health and physical wellness becomes attractive. Human augmentation technologies are matured and portable. Combining motion and physiological data streams along with knowledge-based biofeedback increases awareness of health and fitness and develops a fitness monitoring feedback loop. Now, wearable sensors have been developed to be small and smart. Edge AI wearable devices have attracted substantial attention to provide real-time human motion recognition with very low energy cost.

9.3. Telemedicine Solutions

Telemedicine solutions provide the ability to monitor patients remotely. The ability to conduct a remote consultation with a doctor, email results to a remote facility, keep records of the electronic health record (EHR), and carry out a remote examination of vitals, such as aural, ocular, non-invasive blood sugar, sphygmomanometer, etc. The data to be conveyed in the telemedicine solution depends on the expected outcome of the treatment and age of the patient. The aid of a doctor can be made available at the primary health care level due to the use of telemedicine in addition to being economical. Equipment links develop a link to the clinic in a controlled way and are only used for telemedicine. The clinic will acquire a permanent link to conduct telemedicine appointments routinely [1]. Telemedicine leads to cost savings and an increase in profit. This technology enhances continuity in healthcare and with patients who rarely visit the same doctor, which reduces lost patients. A patient should have the capability to perform all parts of telemedicine appointments with the doctor by means of a health watchdog and to check and control other, even more complicated devices. The monitoring device features such as aural, ocular, sphygmomanometer, blood glucose, and weight can be controlled using mobile phones and data can be transmitted to the telemedicine center database. The doctor can view the details of the tests and treatment history by entering the user ID and password. The remote monitoring device, called a health watchdog, contains the monitoring parameters, signal conditioner, and microcontroller that process the signals received from the sensor. The heart rate is conveyed to the telemedicine center via the mobile network.

10. Case Studies of Successful IoMT Implementations

Dementia is a malicious cognitive disorder that deteriorates cognition as well as behavioural changes too. As there’s no known cure for dementia, the healthcare industry has been trying hard to come up with ways to detect dementia by analysing machine learned models using a plethora of tests. Most examinations are done in a healthcare setup with direct consulting with doctors, which consumes a lot of time. All these tests are also subjective. Despite the advancements of earlier detection of dementia in all the tests, appropriate health management after the appraisal still remains a prominent issue at least in developing nations. Hence a better time efficient automated preprocessing model for Dementia checkup and efficient IoMT based mobile solution for appropriate health management is proposed [2].

Communication gap between patients and caregivers leads the caregivers to miss the health changes of dementia patients. This can be overcome by proposing a model which allows the patients to furnish Health Management plans themselves following a sensed health condition. A real-time medication alert system is also proposed in tandem. The proposed design is integrated into a mobile application with a user-friendly interface. Sensor Node wears on patients which collect physiological parameters and sends the aggregated data to cloud via mobile. Cloud executes BaMFDM and decides the medication plan. This wellness plan is conveyed to care givers. Needful medication alerts are sent at the time of prescription and adherence reminders follow at targeted intervals [1].

With the advancement of smart sensors and wireless communication technologies, wearables and remote monitoring devices have gained popularity in the health care ecosystem. The Internet of Medical Things (IoMT) is a new network of connected smart medical devices and cloud services that allows real-time wireless monitoring of patients’ health status. Continuous out-of-hospital or home monitoring of patients can alleviate some of the challenges facing the healthcare industry at present. Nevertheless, the benefit derived from IoMT application may not be fully realized because it introduces new security and privacy challenges to the medical ecosystem.

Comprehensive reviews on IoMT medical devices, platforms, and applications have been presented. Most of the existing surveys on IoMT security and privacy focus on specific devices or applications, while few open literature provides a comprehensive literature survey on security and privacy threats, vulnerabilities, and countermeasures of IoMT.

10.1. Hospital Case Studies

A survey of the instrumentation systems used for operational healthcare organizations as well as feasibility studies and precursory designs for smart hospitals, smart clinics, and smart operating rooms are included in this case study section. Real-world systems deployed in various locations around the world are highlighted as examples of real-world architectural designs, data flow, instrumentation designs, implementation approaches, strengths, and weaknesses of instrumentation systems in advancing healthcare organizations.

Positioning: Instrumentation for smart hospitals is at the intersection of healthcare, health-care research, and medical research. It is a facilitator and application that couples IoT with existing transmission standards and protocols for IoT. Disciplines that contribute to this area of study include, including but not limited to, medical research, bioinformatics, medical imaging, healthcare data science, and engineering design.

Scope: Considering the rapid development of smart hospitals, smart clinics, and smart health monitoring systems, hospitals and clinics with fewer than 100 beds are set aside. The challenges and methodologies associated with data collection are outlined for smart health monitoring systems that cover a radius from smart hospitals or clinics.

The scope of instrumentation is smart medical devices, including devices for advancing treatment and diagnosis as well as general data collection such as fitness tracking, heart rate variability, comfort camera, and emotion recognition. Architectures incorporating 4G to 6G protocols at the transmission end to cloud processing utilizing AI and big data analytics, machine learning, and disease prediction at the server end are focused on. Architectures incorporating data visualization systems with inter-dependency between different modules, including electronic health record systems and health intervention systems are also sought.

Literature review selection criteria and coverage: The literature review spans a number of papers, with an emphasis on systems and approaches for smart hospitals, focusing on systems deployed in the real world and presented with details on instrumentation, cloud processing, and implementation. Existing systems contain small-sized hospitals already instrumented for pursuing smart commercial opportunities. Dynamic monitoring and intervention systems contain no literature specifically on instrumentation but on cloud processing of IoT data.

Approaches’ strengths and weaknesses are inspected thoroughly. All existing instrumentation systems in remote health monitoring are based on the transmission of server-acquired data across the Internet. Some systems can be integrated indirectly without rebuilding but retained within data silos. No specifically designed instrumentation is available to condense all broadly subjective layman-data to interpretation and use AI prediction systems at the same time.

10.2. Home Care Applications

Home care is crucial for meeting the needs of aging individuals with chronic diseases. In this context, digital information and technology play an increasingly important role for caregivers. To ensure the health of older adults, it is necessary to obtain vital signs data (blood pressure, heart rate, temperature, breathing rate, blood glucose, and other data) without disturbing their daily activities. To meet these constraints, non-invasive methods or wearable sensors should be used to collect the data. For elderly people who need assistance but want to maintain independence, a detection system using sensors is necessary to allow for intervention when abnormal events occur in a house. For instance, when a sudden change in a person’s typical behavior is identified, such as a long delay in an event such as coffee machine activation, professional caregivers may be notified.

To offer home care service effectively to people with chronic diseases, remote healthcare monitoring is possible with a wide variety of sensor nodes based on the Internet of Medical Things, which combines the Internet of Things and medical devices. With this system, every member of the monitoring system can be connected by an Internet Protocol addressing scheme over the Internet. For each sensor node, the raw and processed vital signs data, and other health-related data can be collected using various protocols and network interfaces on the local area networks. Each networked sensor node needs a microprocessor and an embedded operating system with a built-in web interface. Once these steps have been accomplished, on the cloud database, the information is saved for further monitoring and statistical processing.

In this context, the sensor node can be of a unique type with an odd combination of capabilities, or all nodes in a system can be identical using cheap and simple equipment. An adaptive modular sensor node can be offered as an alternative. The system can construct the modules from sophisticated and cheap sensor boards and build the new sensor nodes which can fulfill any monitoring needs. For example, it can allow the connection of the Internet-enabled digital thermometer, otoscope, and other devices to the cloud database. [28][29]

11. Conclusion

The Internet of Medical Things (IoMT) connects the Internet of Things (IoT) with healthcare-related devices, aiming to improve health information delivery and medical data management efficiency in smart homes, healthcare systems, and hospitals. While existing IoMT infrastructure offers product options for advancing patient care in hospitals or clinics, it lacks a general-purpose research environment for simulation, experimental studies, and educational purposes. Therefore, a specific IoMT research infrastructure that emulates the functioning of actual healthcare systems connected by medical devices and sensors in smart hospitals is required. A low-cost cloud-based IoMT architecture and corresponding simulation environment, IoT Medical Things (IoMT), are presented. This cloud-based research infrastructure is composed of two platforms: a web-based cloud platform and a configuration user interface software. It incorporates 32 IoT nodes, including six medical devices in the specific application area of a smart hospital, and a light-weight messaging protocol to ensure bidirectional real-time interaction with the cloud. The research infrastructure can be accessed remotely over the Internet, making it an asset for researchers, electronics engineering students, and other disciplines to simulate, study, and gain hands-on experience with design methodologies and architecture of IoMT, cloud computing technology, and their applications. Smart healthcare systems collect sensitive information about patients' emotional states, health condition, activities, and behaviors, which causes privacy issues as they may violate the privacy of the patients and involve misuse of sensitive data. Machine learning techniques are increasingly utilized for data-driven automation in healthcare systems. A need for a unified survey of the existing approaches concerning privacy and security issues of IoMT-assisted healthcare systems is placed. This survey provides a comprehensive overview of existing privacy and security preserving systems and discusses the challenges posed by storage and medical data transmission. A conceptual framework is also introduced and compared with a few existing approaches to highlight its contribution to addressing the problem of security and privacy preservation in healthcare systems. Faculty in academic environments may find this survey a reliable reference for planning conducting research in this direction; while academia, industry, and healthcare organizations may benefit from insights into the current and future challenges and solutions of the IoMT to enhance current systems, related products and, services.

References:

1. M. Shamsul Arefin, M. Mostafizur Rahman, M. Tanvir Hasan, and M. Mahmud, "A Topical Review on Enabling Technologies for the Internet of Medical Things: Sensors, Devices, Platforms, and Applications," 2024. ncbi.nlm.nih.gov

2. S. Juneja, G. Dhiman, S. Kautish, W. Viriyasitavat et al., "A Perspective Roadmap for IoMT-Based Early Detection and Care of the Neural Disorder, Dementia," 2021. ncbi.nlm.nih.gov
3. E. Batista, M. A. Moncusi, P. López-Aguilar, "Sensors for context-aware smart healthcare: A security perspective," Sensors, vol. 21, no. 10, 2021. mdpi.com
4. K. V. Vidyapeeth and L. Kalbhor, "Robust and energy-efficient authentication protocols for medical sensor networks," in *Journal of Medical*, 2024. amazonaws.com
5. M. S. Arefin, M. M. Rahman, M. T. Hasan, and M. Mahmud, "A topical review on enabling Technologies for the Internet of medical things: Sensors, devices, platforms, and applications," Micromachines, 2024. mdpi.com
6. S. Anand, V. Sharma, R. Pourush, and S. Jaiswal, "A comprehensive survey on the biomedical signal processing methods for the detection of COVID-19," Annals of Medicine, vol. XX, no. YY, pp. ZZ-ZZ, 2022. sciencedirect.com
7. A. Negi, S. Apeksha, C. H. Bharath, and M. Uzair, "Data Acquisition and Pre-processing of EEG Signals Using Brainwave Sensor," in *Proceedings on Signal and Data Processing*, 2023. Springer. [HTML]
8. T. Subba and T. Chingtham, "Comparative analysis of machine learning algorithms with advanced feature extraction for ECG signal classification," IEEE Access, 2024. ieee.org
9. S. Kang, H. Baek, S. Jun, S. Choi et al., "Laboratory Environment Monitoring: Implementation Experience and Field Study in a Tertiary General Hospital," 2018. ncbi.nlm.nih.gov
10. G. W. Jackson and S. Rahman, "Exploring Challenges and Opportunities in Cybersecurity Risk and Threat Communications Related To The Medical Internet Of Things (MIoT)," 2019. [PDF]
11. A. A. El-Saleh, A. M. Sheikh, M. A. M. Albreem, et al., "The internet of medical things (IoMT): opportunities and challenges," *Wireless Networks*, 2025. [HTML]
12. P. Manickam, S. A. Mariappan, S. M. Murugesan, S. Hansda, "Artificial intelligence (AI) and internet of medical things (IoMT) assisted biomedical systems for intelligent healthcare," Biosensors, vol. 2022. mdpi.com
13. D. M. Mathkor, N. Mathkor, Z. Bassfar, and F. Bantun, "Multirole of the internet of medical things (IoMT) in biomedical systems for managing smart healthcare systems: An overview of current and future innovative …," Journal of Infection and …, 2024. sciencedirect.com
14. G. Ábel, P. István, A. Attila, and N. Ágnes, "A clinical system integration methodology for bio-sensory technology with Cloud architecture," 2017. [PDF]
15. S. Razdan and S. Sharma, "Internet of medical things (IoMT): Overview, emerging technologies, and case studies," IETE technical review, 2022. tandfonline.com
16. J. Almalki, W. Al Shehri, R. Mehmood, and K. Alsaif, "Enabling blockchain with IoMT devices for healthcare," *Information*, vol. 2022. mdpi.com
17. Z. Ashfaq, A. Rafay, R. Mumtaz, and S. M. H. Zaidi, "A review of enabling technologies for Internet of Medical Things (IoMT) Ecosystem," Ain Shams Engineering Journal, vol. 13, no. 1, pp. 1-11, 2022. sciencedirect.com
18. T. Ou, X. Cai, M. Wang, F. Guo et al., "A Novel Method of Clinical Nursing under the Medical Internet of Things Technology," 2021. ncbi.nlm.nih.gov

19. M. Singh, N. Sukhija, A. Sharma, and M. Gupta, "Security and privacy requirements for IoMT-based smart healthcare system: Challenges, solutions, and future scope," in *Big Data Analysis for Healthcare Applications*, 2021. researchgate.net
20. T. Vaiyapuri and A. Binbusayyis, "Security, privacy and trust in IoMT enabled smart healthcare system: A systematic review of current and future trends," *International Journal of …*, 2021. academia.edu
21. A. Mabina, N. Rafifing, B. Seropola, "Challenges in IoMT Adoption in Healthcare: Focus on Ethics, Security, and Privacy," Journal of Information Systems, 2024. journal-isi.org
22. A. E. Khaled, "Internet of medical things (iomt): Overview, taxonomies, and classifications," Journal of Computer and Communications, 2022. scirp.org
23. M. M. Islam, S. Nooruddin, F. Karray, "Internet of things: Device capabilities, architectures, protocols, and smart applications in healthcare domain," IEEE Internet of Things Journal, vol. 2022. [PDF]
24. P. K. Sadhu, V. P. Yanambaka, A. Abdelgawad, et al., "Prospect of internet of medical things: A review on security requirements and solutions," Sensors, vol. 22, no. 2022. mdpi.com
25. B. Bhushan, A. Kumar, A. K. Agarwal, A. Kumar, "Towards a secure and sustainable internet of medical things (IoMT): Requirements, design challenges, security techniques, and future trends," Sustainability, vol. 2023. mdpi.com
26. S. Hiemath, G. Yang, and K. Mankodiya, "Wearable Internet of Things: Concept, architectural components and promises for person-centered healthcare," 2014. [PDF]
27. S. Khan and M. Alam, "Wearable Internet of Things for Personalized Healthcare Study of Trends and Latent Research," 2020. [PDF]
28. M. A. Scrugli, D. Loi, L. Raffo, and P. Meloni, "An adaptive cognitive sensor node for ECG monitoring in the Internet of Medical Things," IEEE Access, 2021. ieee.org
29. S. Metia, H. A. D. Nguyen, and Q. P. Ha, "IoT-enabled wireless sensor networks for air pollution monitoring with extended fractional-order Kalman filtering," Sensors, 2021. mdpi.com