Recent Advances in IoT-Based Intelligent Health Monitoring Systems: A Review

[1]Pranali Chavhan, [2]Dr. C. M. Jadhao
[1]Research Scholar, Electronics and Telecommunication Engineering, Mauli Group of Institution's, College of Engineering and Technology, Shegaon, Maharashtra, India
[2]Principal, Mauli Group of Institution's College of Engineering and Technology, Shegaon, Maharashtra, India
pranalichavhan750@gmail.com

* Corresponding Author: Pranali Chavhan

Abstract:

Health sector received immense benefit due to swift advancements in IOT technologies, enabling a long chain of offerings encompassing continuous, real-time and remotely administrated care services. This paper aims to make a comprehensive study of writings concerned with smart healthcare monitoring in IOT contexts. We discuss essential topics as regards IOT health status: architecture, technologies, and applications, and offer a new slant on the concern over the challenges in the context. Such concerns have been put to rest in the design of effective IOT systems translating sensor data into sound beds of health information scattered in the cloud for post-processing through machine learning. Such a walk around several examples of personal and indiscriminate monitoring of operational health and wellness parameters such as heart rate, blood pressure, glucose levels, and body temperature will assist in the early detection and effective medical care management of these parameters. Moreover, the specificity of review is to explore the role of machine learning and deep learning in the enhancement of predicative analytics and decision-making process for smart health care systems. The study also discussed several types of wireless communication protocols, such as Bluetooth, Zigbee, and Wi-Fi and their suitability for health care applications. It provided an examination of principal application areas, such as chronic disease management, elderly care, and remote patient monitoring, with a particular focus on rural and underserved areas.Though significant strides have been made, several challenges still exist, that being data security, privacy issues, interoperability, and energy efficiency of all the devices. The potential solutions and future directions for research are further discussed in relation to the issues. In conclusion, ICT-enabled intelligent health monitoring systems are revolutionary advancements in healthcare delivery that aim at achieving accessibility, efficiency and patient-centeredness.

***Keywords**: Internet of Things (IoT), Intelligent Health Monitoring, Wearable Sensors, Remote Patient Monitoring, Machine Learning, Smart Healthcare Systems*

I. INTRODUCTION

Rapid advances in digital technology have caused enormous positive upheaval in almost all sectors but one that spells potential impact in the healthcare domain. IoT (Internet of Things) tops the list of these sources inasmuch as it integrates devices, systems and services to promote efficient communication and data exchange. In the last few years, the intelligent health monitoring systems of IoT have turned to occupy the centre stage in modern healthcare as they provide all-time, real-time and distant patient monitoring. These systems suspend wearable sensor networks, smartly facilitated interfaces, and advanced communication technologies that measure and analyze the functioning of the patient towards improving the efficiency, accessibility, and the quality of healthcare services [1]. The traditional healthcare systems rely on periodic clinical visits and manually based monitoring, which often causes a delay in diagnosis and prevents immediate medical intervention. Therefore, individuals with chronic diseases or elderly individuals and those living in remote areas or areas devoid of healthcare infrastructure face so many challenges with respect to taking care of their health in such a situation. However, with the implementation of this system, healthcare monitoring using IoT enables continuous surveillance of vital parameters like heart rate, blood pressure, body temperature, oxygen saturation, and glucose levels [2]. This live monitoring of information not only can pick up on early abnormalities but also helps to prevent such in practice and promotes proactive healthcare. Intelligent technologies such as artificial intelligence (AI) and machine learning are slowly added to the existing frameworks to leverage more capabilities of the IoT-based health monitoring systems. These devices are able to gather and analyze all the data pertaining to the health status of a person, thus enabling the identification of patterns, the prediction of potential health risks, and the aiding of decision-making in clinical settings as well. For instance, by employing machine learning algorithms for the detection of abnormalities in a patient's data, a precise picture of the disease progression can be visualized, thereby facilitating the designing of a personalized treatment plan. The integration of aforementioned technologies would help build an environment in which care providers are enabled to render care delivery much more accurate, evidence-based, and patient-centered [3].

Wearables and implantable devices are another vital aspect of healthcare systems built by IoT. These devices, including smartwatches, fitness trackers, and biosensors, are designed to keep track of physiological signals and share the data to centralized servers, such as cloud servers or edge computing systems. An endpoint comprising the data retrieved can be examined by healthcare professionals for diagnosis and treatment and also by the patients themselves for self-monitoring, healthcare, or treatment. The growing interest in the resources indicates a shift toward personalized, decentralized healthcare services. It is absolutely essential to allow for communications technology in the running of these systems of health monitoring based on the internet of things. Wireless protocols such as variations in Bluetooth, Zigbee or Wi-Fi are generally applied to enable information transactions in between devices and healthcare platforms [4]. Development in mobile networking supports data communications actively in a real-time and fail-overs when used with 4G and 5G citifying the long-term speed, reliability, and scalability. Restrengthening this import is the fact that the developments make sure that health data could be sent clean, free-standing, and hence faster, this enhancing healthcare responsiveness. Fig. 1 illustrates the overall architecture of an IoT-based cardiac monitoring system, where sensors collect heart data, transmit it via network connectivity, and enable real-time analysis and remote healthcare monitoring.

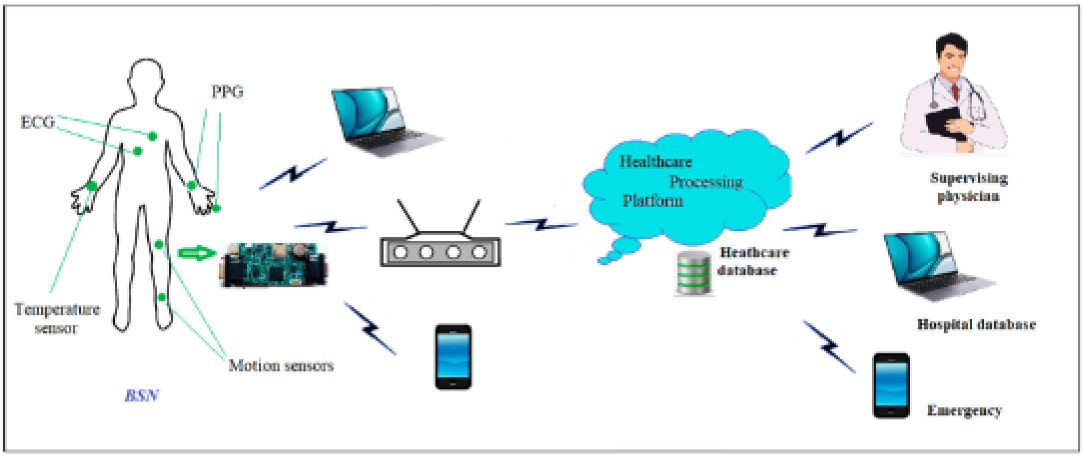

Fig. 1. General schema of IoT-based cardio monitoring system. [4]

Additionally, cloud and edge computing are vital to the advance operation of smart health monitoring. Through cloud platforms, it provides vertible storage and computing resources to marshal large-scale health data, whereas edge computing allows to process data closer to the source while reducing latency and bandwidth requirements. This is ideally a combined setup to provide for the speed of data analysis, making real-time decisions, and giving better system performance. It will further lead to the emergence of advanced healthcare applications, including telemedicine, remote diagnosing, and emergency response systems. There are multiple benefits that are offered with the use of IoT-based intelligent health monitoring; however, these are accompanied by several important challenges [5]. Data security and privacy remain major concerns, given the fact that sensitive health information moves across diverse platforms. The confidence, integrity, and continued availability of this data play a critical role in ensuring trust among patients and the satisfaction of regulatory standards. Additionally, the interoperability of various devices and systems restricted communication and the smooth integration of data.

Energy efficiency is another significant concern for wearable devices, particularly the ones powered by rechargeable batteries and envisaged to operate for an extended time period. The use of low-power communication protocols and energy-efficient hardware design is necessary if the deployment life of said devices is supposed to be elongated while ensuring higher levels of usability [6]. The accuracy and reliability of sensor data must be maintained such that erroneous conclusions related to medical problems are averted, inviting a need for continued research and multispecialty collaboration. Health monitoring based on IoT has been overcoming significant leaps in recent years thanks to sensor technology advancements, data analytics expansion, and innovations in communication infrastructures. Smart healthcare ecosystems that integrate various technologies and stakeholders have accelerated the development and deployment of intelligent monitoring solutions further. These systems have shown to be especially valuable during global health crises like pandemics, where remote monitoring and telehealth services are vital in relieving the burden on healthcare facilities by minimizing physical contact [7]. The IoT-based health monitoring system presents a game-changing way of delivering healthcare and offers lots of advantages in terms of offering quality healthcare, accessibility, and real-time analysis of patients' data streams. Moreover, these systems aid real-time analysis of data, continuous monitoring, and personalizing health services, and are key in increasing the health outcomes and decreasing healthcare cost very rapidly. However, the problem discussion on the challenges in health-data management and its subsequent ethical use remains greater challenges towards implementation. Thus, this paper reviewed recent advances, practical applications, challenges, and future direction of IoT-based intelligent health monitoring system for the benefit of researchers and practitioners [8].

II. OVERVIEW OF IOT IN HEALTHCARE

Service outages are common in IoT deployments and efforts toward creating useful operational security frameworks continue to fail. Building on the dealings between IoT nodes and the lack of compatibility among communication protocols, one or two incidents are critical disasters to IoT visibility and usability. Enacting legislation aimed at minimizing IoT-related operational violations might well be the key to finding a broader audience for Internet security specialists, thereby helping in the establishment of operationally secure IoTs [9].

At the center of IoT-based healthcare systems lies the installation of smart sensors and wearable devices that monitor physiological parameters, such as heart rate, blood pressure, body temperature, oxygen saturation, and glucose levels. Normally, these devices are embedded in wearable gadgets such as fitness trackers, smartwatches, and specific clinical equipment. The collected data is shared using communication technologies with a central platform, where the data is saved, processed, and analyzed. This perpetual stream of data reaching healthcare providers, who, in turn, are ready to gather a much deeper understanding of the health status of patients, which helps in early diagnosis and prompt intervention. One major aspect of IoT efficiency in healthcare is extending remote patient monitoring [10]. This could come very handy in people having chronic diseases, elderly patients, and in people living in rural areas, or those belonging to underserved groups owing to limited patient access to healthcare facilities. With the real-time monitoring and information sharing allowed by the IoT system, the needs for frequent hospital visits are minimized, and an opportunity has been created for patients to go in for medical help right in the comfort of their homes. This actually improves convenience for the patient, while lessening the strain that the healthcare structure is burdened with. AI finds its applications in optimizing many other applications in clinical workflows and hospital management [11]. The smart hospital outlets instruments and devices for IoT aggregation to survey and scrutinize security and environmental concerns, such as temperatures containers and bottles. IoT-based asset trackers, for instance, help healthcare providers track down vital items rapidly and thereby reduce the time to institute a programmed course of medical care for sick patients. Additionally, smart beds and monitored devices can be furnished with the technologies to monitor patient movements and alert concerned personnel in situations of severe emergency apprehensions. These applications are geared toward popularizing operational efficiency of hospital management and patient security [12].

The union of IoT with technologies like artificial intelligence (AI) and machine learning (ML) only extends its potential in healthcare. IoT-derived data can be fortified with AI analytics able to gauge big data signals to detect patterns, anomalies, and possible conditions of health risk. An illustration could be forecasting disease progression by a predictive model, armed with the ability to exploit historical and real-time data for excelling in its prediction of adverse conditions such as cardiac arrest or diabetes complications. This data-driven approach allows the healthcare ecosystem to reach well-informed decisions and personalized treatment itself [13]. One of the most important parts of the IoT concept in healthcare, after having connected devices for communication and data generation, is edge and cloud computing. Cloud computing harnesses scalable storage and computational resources that are essential for processing huge amount of health data, while edge computing ensures the actual processing is done nearer to the data generation source. By bringing down latency and enabling in-the-moment responses, the innovations in technology are fundamentally streamlined vis-à-vis real-time decision making, thus successfully boiling down dependence on centralized systems. The unity between cloud and edge computing technique facilitates the effective handling of data and the evolution of malleable and secure healthcare applications [14].

New communication technologies provide advanced medical care that allows the seamless transfer of data among devices and platforms in IoT. To enhance connectivity, several wireless protocols, such as Bluetooth, Zigbee, Wi-Fi, and cellular networks, are applied. Speed, dependability, and scalability of IoT-based systems have all been improved with more modern wireless technology, like 5G. Industrial standard certification brings comparatively reliable communication solutions between technologies, further complementing the technology used to support private and connected technologies. The speed, reliability, and capability offered by new-age wireless technologies will improve high-speed, real-time data transfer, crucial for time-sensitive healthcare systems [15]. The key challenge resides in data security and privacy considerations, aspects linking both in the signal processing and computer technology of being able to transmit as well as reside through competent devices and platforms. Secure data transfers and adherance to regulatory requirements are key to keeping patients confident. The complexity is further compounded by interoperability- the devices' heterogeneity and communication protocols make smooth integration an nearly impossible task within different systems.

The main focus is on the energy efficiency of wearable and portable gadgets dependent on battery power, and the related usability and durability during prolonged use. For this project, it is compulsory to work both on making energy-efficient hardware and communication protocols. The data from sensors are extremely essential to ensure the accuracy and reliability in order to prevent incorrect diagnoses or decisions in medicine [16]. In recent years, the role of IoT has become more essential in the healthcare sector with the increasing demand for remote and contactless medical services. As the COVID-19 pandemic came into being, healthcare solutions powered by IoT were first of all helpful in tracking patients and health conditions and restricting the spread of diseases. The exposure resulted in an upsurge in R&D toward developing IoT-borne healthcare solutions.

III. Architecture of IoT-Based Health Monitoring Systems

The architecture of health-based IoT monitoring systems is predominantly formed by essentially multilayered structures allowing the synthesis of data from the first stages of gathering, transferring, storing, and using the details of diagnosis measures and treatments. These layers impart efficient systems, namely scalability and near real-time responses, with their added benefits. These layers are supposed to carry the single activity of capturing the physiological data of the system and providing actionable healthcare insights to healthcare providers and family elements. The major ones are the sensor layer, network/communication layer, data-processing layer, and application layer of these [17]. Together, they form an integrated ecosystem to support medical care for it while remaining in hand's length from video or correct decision-making, conceivably providing an innovation of the health system.

a. Sensor layer (wearable devices)

Threats to privacy exist when dealing with security issues in Internet of Things-based systems, on which the protection of patient privacy relies. Security measures must be implemented properly, including proper encryption of data for either manual transmission or authenticated keys. User B is an authentication or ticketing agent that enables the monitoring of all communications through the architecture while ensuring compliance with security rules. Furthermore, stringent control of access of data and networking equipment is necessary for privacy protection purposes [18]. Data must not be transmitted out to unintended sites, which are achievable if automatic data exchange is disabled until authentication is met within the established parameters.

Lightweight, portable, yet energy-efficient, wearables are meant to be comfortable and long-lasting. Advances in sensor technology used in health monitoring have been a major contributing factor in increasing data accuracy and reliability. In the majority of such systems, microcontrollers and embedded systems are used to filter and preprocess some initial data. The sensor layer is thus of high importance with respect to real-time health monitoring, as it will provide the basis for conducting intelligent analysis later on in assisting the subsequent layers.

b. NETWORK/COMMUNICATION LAYER

The network or communication layer is responsible for sending the data collected from the sensor layer to centralized systems where the transferred data is then processed. This assures the seamless connection of devices, gateways, and servers using various wired and wireless communication technologies. Commonly used communication protocols in IoT-based healthcare systems are Bluetooth, Zigbee, Wi-Fi, 4G, and 5G cellular networks.

The communication layer, a fundamental component of any IoT system, is important to assure secure, reliable, and low-latency data transmission, which is absolutely critical for real-time health monitoring applications. It often consists of gateways or of various intermediate devices aggregating data from multiple sensors and transferring it to edge platforms or cloud. The more efficient the mechanism for data transmission, the more the consumption of bandwidth and energy can be reduced, especially where battery-operated equipment is concerned [19]. Besides, this layer secures data security and privacy aspects through the implementation of encryption and authentication techniques. Above all, this communication layer is a simple bridge connecting physical objects to digital health care systems.

c. DATA PROCESSING LAYER (CLOUD & EDGE COMPUTING)

The data layer is in control over storing, analyzing, and managing the vast amounts of health data that are produced by IoT devices. Both cloud computing architectures and edge computing-based technologies are involved in the speedy and accurate processing of data. Scalable storage and very potent computational force are made available by cloud platforms in order to give healthcare workers access from every conceivable place around the world for data surveillance.

Edge computing is an add-on for cloud computing in processing data near the source, lowering the latency and cutting down the continuous data commutation. This is very important for time-sensitive health applications such as emergency management and critical care [20]. To deduce actionable intelligence, detect outliers, and boast predictive health hazard, the expert host for data analytics would use highly developed techniques: artificial intelligence and machine learning. The data processing layer ensures raw sensory data undergoes a transformation into actionable information through accurate diagnosis and informed decision-making.

d. APPLICATION LAYER

The app layer serves as the topmost layer of the IoT health monitoring system, where processed data is visualizable to consumers in a way that would be understandable or easy to access. This layer hosts many different health applications, dashboards, and interfaces for patients, doctors, and health administrators. This layer allows the visualization of health data, alerts, and notifications in real-time, which would enable timely medical intervention.

The application supports a plethora of functionalities which include remote patient monitoring, telemedicine, chronic disease management, and fitness tracking, enabling healthcare professionals to access patient records, analyze trends, and make informed clinical decisions, and patients to monitor their own health statuses and receive personalized recommendations. Moreover, this layer in most cases interfaces with electronic health record (EHR) systems to ensure sustainability of complete medical histories. So the application layer will furnish user-friendly and effective healthcare solutions ultimately enhancing medical outcomes and healthcare efficiency.

IV. ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING

While Artificial Intelligence (AI) and Machine Learning (ML) gets integrated with the spectrum of IoT technologies, modern healthcare systems are influenced to a greater scope. Healthcare operates on IoT, generating an overwhelming cascade of real-time data from wearable devices, sensors, and medical machinery. Nonetheless, significant raw data amounts are of little value if it is not acted upon; thus, they serve only to thicken the dust of oblivion. AI and ML are in essence at the forefront of this data analysis, and are the reasons behind intelligent decision-making, predictive analytics, and automation within healthcare environments. "AI" denotes the manner in which human intelligence is simulated within machines, allowing systems to perform tasks such as learning, reasoning, and problem solving. Machine learning, a subfield of AI, develops algorithms that are able to learn from data, improving their performance over time without being explicitly programmed [21]. In IoT-based health systems, machine learning models are trained on large-scale datasets collected from patients to account for patterns, detect anomalies, and make inferences about health conditions, particularly useful for early diagnosis and disease prevention. Among its numerous applications, one of the most critical advantages of AI and ML in healthcare in IoT is in predictive analytics. It is through ML algorithms which accomplish predictive analytics by analyzing historical and real-time patient data, achieving predictive models that can predict potential health risks and disease progression. For example, predictive models can identify symptoms early, with respect to chronic conditions such as diabetes, cardiovascular diseases, and hypertension. It was assumed that physicians could intervene in time, before the condition worsened and became so critical that in the long-term, the treatment of patients would be much better and less costly for the healthcare system. In order to this, predictive analytics also helps in the grounds of personalized medicine by enabling the customization of treatment to individual patients' data and risk profiles.

Another important application is the patient monitoring systems that do an anomaly detection. So, essentially, IoT devices keep track of the vital signs like heart rates, blood pressure, oxygen saturation, and body temperature. This continuous stream of data can be analyzed by ML algorithms to show unusuweird patterns or sudden changes that point to medical emergencies. Say if there is an unusual rise and fall of heartbeat patterns, they could alert the caregivers for immediate intervention. Thus, elderly patients and sick patients are benefited by constant monitoring and alert [22].

AI and ML have a role and importance in medical diagnosis and doctor Decision support systems. Deep learning models and other advanced algorithms are used to analyze challenging medical data, like electrocardiograms (ECG), medical images, and patient records, to aid the doctors in diagnosing diseases. The systems will be able to provide insights based on data to reduce human errors and improve diagnostic accuracies. Such decision support systems being integrated into IoT-based healthcare and can communicate with real-time data flows that therefore will allow you to generate dynamic and location aware medical decisions. Moreover, in the analysis of medical data toigether with clinical notes, biographies, and patient reviews, AI models using natural langunge processing are found useful. NLP helps interpret data automatically and structure these as an easy-to-analyze file-naming method. It works wonders in enhancing efficacy in health systems automating documation and providing easy access to data. AI sypported chat agents and virtual assistants are in widespread use for basic medical counselling, scheduling appointments, and answering patient queries.

Meanwhile, edge AI gained even more importance in IoT-based health-care scenarios like those where ML models are run directly on edge devices such as wearable sensors or gateways. Consequently, processing data locally is essential in killing latency and allowing a minuscule amount of data to be transferred to the cloud. In the critical health care sector, especially when it is necessary to monitor patients in intensive care units, and presumably in distinguishing elderly falls, it will help to have real-time decision-making available. In so far as patient data are handled within the network of the local receivers, this can be a way to strengthen security by providing misdirection of protected information. Although there are immense benefits that come with the incorporation of AI and ML into IoT healthcare, numerous challenges also exist. One of such challenges is the issue of data privacy and security [23]. As a responsible party, all the byways of this sensitive health intelligence are deposited into multiple platforms. As a matter of urgency, the handling of data securely and making compliance to governance standards a strict practice are warranted to secure trust from the patients. Again, the data quality and reliability have come to establish the whole gamut for the ML models. Certainly, incorrect or incomplete data leads to disproven predictions and, by deceptive extension, unsafe decisions.

One more pain point is the readability of AI models- particularly deep learning algorithms-as they are termed black boxes. In the medical field, it is necessary that clinicians know how and why a model made a certain decision. To this end, there is an increasing focus on XAI-best practices as far as ray of explanation and accountability in decision-making are concerned. In order to work more efficiently, AI integration should be subject to the standards and interoperability among different devices and platforms. Some of these challenges are progressively being catered to by recent AI and ML advancements such as federated learning and transfer learning. Federated learning enables model training collaboration without the necessity of raw data being exchanged, thereby enhancing privacy and security. Transfer learning enables models to use pre-trained knowledge to lower the requisite of size of datasets and computational resources. All these advancements would make the AI-based healthcare solutions faster and safer. Table 1 presents a comprehensive overview of the roles, techniques, applications, benefits, and challenges of Artificial Intelligence and Machine Learning in IoT-based healthcare systems [24].

Table 1: AI and ML in IoT-Based Healthcare Systems

Aspect	Description	Techniques/Methods	Applications in Healthcare	Benefits	Challenges
Predictive Analytics	Uses historical and real-time data to predict diseases and health risks	Regression, Decision Trees, Neural Networks	Early detection of diabetes, heart disease, hypertension	Early diagnosis, preventive care, reduced costs	Requires large datasets, risk of inaccurate predictions
Anomaly Detection	Identifies abnormal patterns in patient data	Clustering, SVM, Deep Learning	Detecting irregular heart rate, sudden health deterioration	Real-time alerts, improved patient safety	False positives, data noise issues
Clinical Decision Support	Assists doctors in diagnosis and treatment planning	Deep Learning, Expert Systems	Disease diagnosis, treatment recommendations	Improved accuracy, reduced human error	Lack of transparency (black-box models)
Medical Data Analysis	Processes structured and unstructured health data	NLP, Data Mining	Analysis of clinical notes, EHRs, prescriptions	Efficient data handling, automation	Data privacy concerns, complexity
Remote Patient Monitoring	Continuous monitoring using IoT devices	ML algorithms, Time-series analysis	Monitoring elderly and chronic patients	Reduced hospital visits, real-time tracking	Connectivity and reliability issues
Personalized Healthcare	Tailors treatment based on individual data	Recommendation Systems, Predictive Models	Customized treatment plans, lifestyle suggestions	Better patient outcomes, targeted therapy	Data variability, model bias
Edge AI	Processes data locally on IoT devices	TinyML, Embedded AI	ICU monitoring, fall detection systems	Low latency, enhanced privacy	Limited device resources
Natural Language Processing (NLP)	Extracts insights from textual medical data	Text Mining, Sentiment Analysis	Chatbots, medical record analysis	Automation, improved accessibility	Language ambiguity, data quality issues
Security & Privacy Enhancements	Protects sensitive healthcare data	Federated Learning, Encryption	Secure data sharing in hospitals	Improved privacy, compliance	Implementation complexity
Explainable AI (XAI)	Provides transparency in AI decisions	SHAP, LIME	Interpretable diagnosis systems	Trust and accountability	Trade-off with model performance

V. APPLICATIONS OF IOT-BASED HEALTH MONITORING SYSTEMS

Health monitoring systems established on the Internet offer a slew of changes to modern medicine functioning by allowing patient monitoring at remote sites in real time, thus giving hospitals improved access to medical efficiency. Amongst its many applications, remote patient monitoring, the healthcare provision model involves patients using IoT devices for keeping up-to-date on biometric information, regarding the heart rate, blood pressure, oxygen level, and temperature. This has enabled a unique context to the healthcare providers' management oversight of their clients, which reduces immediate medical appointments. With numerous chronic diseases like diabetes, cardiovascular diseases, and respiratory-associated diseases at stake, medical aides like these help to monitor the progress of treatment.

Among other uses, the management of chronic diseases is one in which the application of IoT systems helps keep track of and treat the patients throughout the long term. By analyzing data gathered over time, healthcare professionals can study patterns and adjust treatment schemes accordingly. For example, there have been examples of IoT-based glucose monitors that provide real-time information to diabetes patients by helping them regulate their own sugar levels - which also prevents complications. Similarly, IoT devices are popularly used in blood pressure and cardiac conditions management, maximizing continuous feedback and alerts. Health monitoring based on IoT also plays an integral role in elderly care. Due to escalating aging populations, the need for the protection and well-being of elders necessitates systems such as these. Wearable devices with fall detection sensors, GPS tracking, and emergency alert systems utilize quick response options in the event of an emergency. Such systems make it possible for elderly individuals to live independently, but once an unfortunate event like a fall occurs, help is quickly at hand. IoT has given fitness and health tracking a major boost. Fitness trackers, like health bands or smartwatches, monitor physical exertion, sleep patterns, and calorie intake, thereby providing an impetus for individuals to practice healthy living. They provide personalized information and suggestions to get support and assistance in marriages and fitness goals and also to prevent lifestyle-related diseases [25].

Telemedicine is one of the major applications of IoT in healthcare. Patients can refer to healthcare professionals by connecting IoT devices to communication technologies; they can share real-time health data and medical advice from doctors, without needing to visit a hospital. Sometimes this is achieved in places with limited accessibility to healthcare, such as rural areas. IoT-based telehealth solutions can increase patient convenience and reduce the burden over the healthcare infrastructure. Additionally, IoT systems have found widespread use in hospital management and clinical settings. IoT devices aid tracking medical equipment, observing a patient's condition, and efficiently managing resources in a smart hospital environment. For instance, IoT-enabled beds can track patient movement and vital signs alerting the clinical staff about abnormalities. Asset tracking helps in the quick location of crucial equipment, hence minimizing delays in treatment and increasing operational efficiency. The people typically monitor the IoT with medical emergency facilities. In a critical situation, those devices will put the care providers and other emergency personnel to alert inattentive to abnormal health conditions. Time-to-emergency response might make a difference, especially in heart attacks, strokes, and accidents.

In essence, the health monitoring systems of IoT turned the shaping of healthcare the most proactive, most personal, and most reachable option to the use of technology. Usually applications enhance patient function and lessen the cost of medical service provision for better health management.

Recent Advances and Research Trends

Technological advancements in sensor technologies and computing platforms have become the primary motivators for the rapid development of ubiquitous IoT health monitoring systems. This is because of the progress made in sensors, artificial intelligence, communication networks, and analytic applications. The most outstanding development goes toward the integration of highly advanced wearable sensors providing higher accuracy, miniaturization, and energy efficiency. The modern wearable devices are designed to monitor several physiological parameters at one time, thus providing a real-life view of the health state. Besides flexible and implantable sensors, these studies also looked at comfort in patient discomfort in continuous monitoring. It is necessary to incorporate both supervised and unsupervised learning algorithms as well as techniques such as deep learning for the creation of more widely accepted applications. Additionally, the combination of reinforcement learning with sense-making techniques from data would be one of the more interesting and even groundbreaking achievements. Training with increasingly complex levels of singularity ultimately requires improved methodologies compared with the current ones. Future intelligent systems may be based on symbolic reasoning or the induction process, which in some ways provides general solutions to problems.

Edge computing has been distinguished as a very important trend in healthcare coming from the Internet of Things, which is also seen by the drawbacks of being cloud based. Therefore, machines process the data near the source to control data latency and pave the way for real-time decision-making while cutting down on the required amount of bandwidth. This is especially plausible in critical moments in healthcare where an instantaneous reply is necessary. An architectural combination of cloud and edge thus produces a hybrid solution that can truly balance the epic proportions of performance and scalability.

Implementation of new generation technologies including 5G network further fast-tracked IoT adoption in healthcare. The technology meets higher data transfer speed, low latency, and the ability to support many devices in a single network. This capability provides for interoperable communication among IoT systems and healthcare platforms to offer real-time monitoriong and remote diagnostics. It will be of great interest if long-range and energy-efficient communication will soon be available via LPWAN. Likewise, use of blockchain technology to increase security regarding data is also one of the trends currently unfolding in medical-cum-healthcare systems," remarked the specialist with regards to executing any such idea. The blockchain will provide non-centrally-based access and security for medical data. By ensuring transparency and trustworthiness, this technology ensures the security of electronic health records and allows for secure data exchange amongst different care providers. In recent contributions, interoperability and standardization have been much stressed. Common protocols and frameworks are being put into place so that there can exist seamless integration between heterogeneous devices and systems. This integration is needed to create an organic healthcare ecosystem where data is smoothly and instantaneously shared and put to use on various platforms. Also, the commencement of the COVID-19 pandemic has really spurred the adoption of monitoring-oriented IoT systems, elevating remote patient treatment and contact tracing into the dallies of healthcare providers everywhere. Researchers are now in hot pursuit to develop some of the most powerful, scalable, and resilient systems that can handle the vast magnitude of continuous data within real-time monitoring during health crises. Table 2 summarizes the key challenges and limitations of IoT-based health monitoring systems, highlighting issues related to security, interoperability, cost, and system performance.

Table 2: Challenges and Limitations

Challenge	Description	Impact on Healthcare Systems
Data Security and Privacy	Risk of unauthorized access to sensitive health data	Loss of patient trust, legal issues
Interoperability Issues	Lack of standardization among devices and platforms	Difficulty in system integration
Energy Consumption	High power usage in wearable and IoT devices	Reduced device lifespan
Data Accuracy and Reliability	Inaccurate sensor readings or data noise	Incorrect diagnosis and treatment
Scalability Issues	Handling large volumes of data and devices	System performance degradation
High Implementation Cost	Expensive devices and infrastructure	Limited adoption in low-resource settings
Latency and Connectivity Issues	Delays in data transmission	Ineffective real-time monitoring
Regulatory and Compliance Issues	Strict healthcare regulations	Slow deployment of systems
User Acceptance and Adoption	Resistance from patients and healthcare providers	Reduced effectiveness of systems

VI. CONCLUSION AND FUTURE WORK

This review highlights the significant advancements in IoT-based intelligent health monitoring systems and their transformative impact on modern healthcare. The review lays out a comprehensive system of architectures, technologies that power things such as artificial intelligence and machine learning, as well various applications, including remote patient monitoring, chronic disease management, and elderly care. Among the various approaches discussed, the integration of IoT with AI and edge computing appears to be more efficient and effective, offering real-time analysis, improved accuracy, and faster decision-making compared to cloud-based systems. Also, the review suggests that combining wearable sensor-based monitoring capabilities with machine learning techniques may provide good significance in early disease prediction or personalized healthcare services. Intelligent systems are significantly better than traditional healthcare models by monitoring continuously, reducing hospital visits, and improving patient care. However, data security, interoperability, and energy efficiency remaindes. Future work should focus on designing architectures that are secure and scalable and protect privacy while sustaining a high system performance.

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