Role of IoT in Healthcare: A Comprehensive Review

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Abstract Internet of Things (IoT) has been continuously bringing vast technological advancements in our daily lives, thereby serving to simplify our life and making it more comfortable through its innumerable applications. IoT offers numerous benefits in the field of healthcare by reducing the cost of services and by offering care to patients that require intensive care or remote assistance. This provides numerous opportunities to enhance the quality of healthcare and reduce the cost of healthcare services. Lack of medical services assets and rising clinical costs make IoT-based innovations necessarily be customized to address the difficulties in medical services. IoT provides unprecedented advancements in the field of healthcare. This paper examines the various roles of IoT that are revolutionizing the healthcare domain by imparting extensive benefits to mankind by providing practical and affordable medical assistance. This paper presents IoT in healthcare, literature review of work carried out in this area, various challenges faced, and future scope.

Keywords IoT · Smart devices · Healthcare · Smart hospital

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1 Introduction

The term "IoT" alludes to a wide vision, where "things" including the everyday articles, environments, and places can be inter-connected with each other by means of the Internet. IoT refers to an "intelligent" network that connects all the things with the internet, for communicating and exchanging the information according to specified protocols. This enables the system to track, monitor, identify, locate, and manage things with great efficacy, thereby developing a new information society.

The rapid evolution of IoT is due to numerous benefits offered by IoT including reduced cost, more accuracy, and growth in digital economy. IoT has brought numerous benefits to the mankind and many organizations by providing services in real time. For the domains that need the data to be continuously controlled or monitored, IoT-based systems are becoming immensely beneficial. Internet of Things (IoT) is extensively adopted in numerous applications and its significance is increasing in our daily life. IoT-based systems are prevalent for home-automation systems, fitness tracking system, smart cities, smart education, environment protection, health monitoring, and smart agriculture. IoT is creating a connected community by enhancing human interaction with the intelligent things.

IoT in the field of education provides communication among a variety of sensors, controllers, and objects. IoT-based systems enable efficient and comfortable learning by using intelligent devices, learning analytics, wearable gadgets that are used in Smart classrooms, thereby providing a Smart learning environment. IoT is also successfully implemented in environmental applications for real-time analysis of air/water pollution, temperature, monitoring harmful radiations. Smart cities are using IoT for efficient management of water resources, waste materials, energy conservation, and smart buildings. Real-time information can assist in parking facility, traffic management, and smart assistance in case of road accidents. Some applications of IoT are summarized in Fig. 1.

2 IoT in Healthcare

IoT has a far-reaching impact on monitoring patient's health and for providing essential services to patients. IoT has brought "Smart" healthcare system in the medical domain, comprising sensors having smart capabilities, remote server, and network. The system is intended to impart numerous features, suggestions for basic treatment, and continuous monitoring of patient's health. Numerous devices like ventilators, infusion pumps, MRI machines, etc., are connected via hospital network, thereby having the ability to improve efficacy and quality of analyzing and providing medical data.

The usage of wearable computing devices and various kinds of sensors is also increasing. Various devices are commercially available that are beneficial for tracking

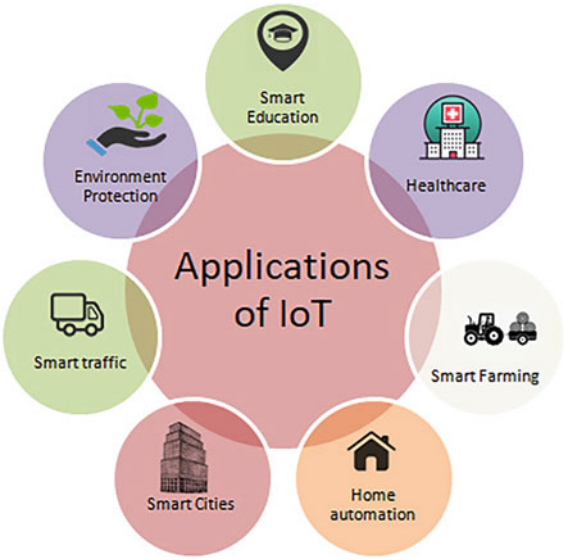

Fig. 1 Applications of IoT

physical activity, biometric measurements, personal healthcare and to adjust environmental control. Moreover, predicting chronic disorders in initial phase is exceptionally crucial. The "Smart" devices are even able to sense and store these biometric measurements over the time, thus enabling the analysis of results. This provides enormous opportunities to the medical professionals for diagnosing and treating distant patients suffering from chronic diseases or multimorbidity. With help of remote monitoring, their visits to hospital and hospital re-admission can also be reduced.

Smart hospital can be referred to as an ecosystem comprising of people, servers, equipments, sensors, actuators that are inter-connected and managed in a unified manner for efficient utilization of resources [1]. Body area sensors, wearable gadgets, and smartphones play a vital role in the IoT m-health ecosystem [2] (Fig. 2).

Various devices like sensors, cameras, actuators are inter-connected to collect patient's data. For further processing, the data is converted to digital form and stored on the cloud. Then the data is analyzed for efficient decision-making by the experts. Wearable devices like fitness bands, glucometers, heart-rate monitoring system help the healthcare professionals to proactively monitor patients' conditions. Continuous monitoring of data is also helpful in prognosis of diseases at initial stage and providing proactive treatment. IoT sensors are beneficial to elderly persons also, as their health can be monitored by healthcare professionals. Moreover, numerous equipments including oxygen pumps, wheelchairs, etc., are tagged with sensors for managing and tracking their real-time location. As the devices are inter-connected, therefore they can be managed with efficacy. Ingestible sensors are also emerging as useful technology for detecting gastrointestinal problems. Many IoT-based hygiene monitoring equipments are used in hospitals for maintaining health and safety of patients. WBAN (Wireless Body Area Network) comprises numerous wearable

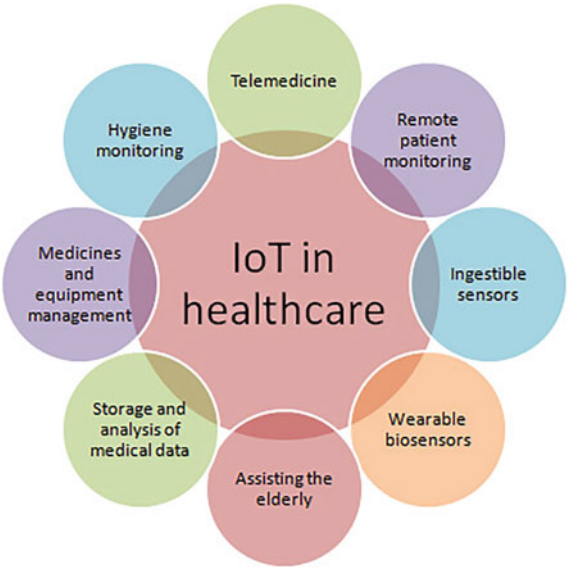

Fig. 2 IoT in healthcare

sensors that are capable of measuring physiological parameters like blood pressure and body temperature. This information is transmitted to gateway server using Bluetooth connection. Then this data is stored on cloud-based remote server to enable it for retrieval later on. With help of content service application, medical staff is able to access the stored data.

RFID (Radio Frequency Identification) technology uses radio waves for transferring data using electronic tag that is attached to the objects, thereby being able to find and track objects within the infrastructure. It is also beneficial for retrieving patient information from database on the basis of unique ID that is generated by RFID technology [3]. In the recent times, many smart devices are available that are able to monitor patients' health parameters, e.g., pulse rate, blood pressure, level of sugar in blood, body temperature, etc. IoT-based systems connect the available resources as a network for performing various activities such as diagnosing, monitoring, and obtaining valuable real-time data, by reducing direct contact of patients with doctors.

Advancement in the field of IoT has led to expansion of portable, affordable, and user-friendly devices. These devices have sensors to gather patient's information. Some of the common IoT healthcare devices are listed in Table 1, that are commercially available to gather patient's information for prognosis of diseases, real-time monitoring of patient's health and alert the patients and medical professionals in case of any medical emergency situation.

Table 1 Common IoT healthcare devices

IoT device	Application
Glucose level sensing	IoT-based wearable gadgets for collecting the data of glucose level in blood are being used that enable the medical staff to access real-time data of patients. These devices can also alert patients if the glucose level is too high or too low
Blood pressure monitoring system	IoT-based gadgets that are wearable and cuffless are used to measure diastolic and systolic pressure, save the information for real-time monitoring
Heart-rate monitoring system	Small IoT-based devices are offered for continuous heart-rate monitoring for real-time diagnosis of heart abnormalities
Body temperature monitoring	Light-weight wearable sensors are being used for real-time monitoring of body temperature for adults as well as infants
Oxygen saturation monitoring	IoT-based devices provide non-invasive methods for real-time monitoring of pulse and blood oxygen levels that can transmit the information and also alert the patients and doctors if a critical value is obtained
Depression/mood monitoring	These devices can gather the information about patient's mental well-being by analyzing patient's heart beat and blood pressure
Ingestible sensors	These are small IoT-based devices that can be swallowed with ease and gather information about patient's digestive and other systems
Smart wheelchairs	For patients with restricted mobility, Smart wheelchairs provide easy gestures for controlling the wheelchair, also possessing feature of obstacle detection. Caregivers can also navigate and track the movement of smart wheelchairs
Activity tracking	Using IoT-based wristband sensors or smartwatches, patient's activity level and diet intake can be monitored

3 Literature Review

The developing countries have high death rate, as there is lack of timely available treatment. However, majority of deaths can be prevented by providing adequate healthcare facilities to patients by real-time monitoring and tracking patient's health. In this section, the literature review is presented, how IoT contributes to the field of healthcare. For chronic diseases, smart system for monitoring patient's health is designed that obtain sensor data. Using the body sensor network and the wireless body area network, health status can be analyzed using Bluetooth technology and ZigBee. Moreover, during emergency situations, the system is capable of sending emergency alert to monitoring authority, family relative, and specialist doctor [4].

A wearable and flexible real-time ECG monitoring system is proposed that is integrated on a T-shirt. The system is by a rechargeable battery of 240 mAh, also

equipped with a flexible solar energy harvester. For collecting the patient's ECG data, a biopotential analog frontline chip is used [5].

A system is designed for cancer prediction using IoT, which extracts details of blood results and tests whether it is "normal" or "abnormal". In case of patients suffering from cancer, the blood test results are encrypted and for quick reference, these are stored on the cloud. AES algorithm is used to provide security and authentication for handling the patients suffering from cancer [6]. A machine learning-based system is proposed for early-stage detection of breast cancer for efficiently classifying benign and malignant people in the environment of IoT. For testing the proposed method, Wisconsin Diagnostic Breast Cancer dataset is used. The proposed system is reliable for IoT in healthcare [7]. A model is proposed for prognosis of COVID-19 patients in smart hospitals. The model is based on IoT and Machine Learning that can be used for clinical decision support [8]. An IoT-based predictive model is proposed [9] using fuzzy cluster-based augmentation and classification that predicts lung cancer by continuous monitoring, that improves healthcare through medical instructions. To extract the transition region from lung cancer images, Otsu thresholding method is used. For cancer patient's rehabilitation scheme, a user-friendly intelligent system [10] is designed. The system is beneficial for doctors for selecting personalized rehabilitation and nutrition programs, that are apt for patients in rehabilitation treatment's later stage. For this purpose, BAS and CNN algorithms are used under IoT framework. For hospitals and nursing institutes, an IoT aware smart architecture is proposed [11] that is able to automatically monitor, track patients and biomedical devices. The system relies on WSN, RFID, and smart mobiles that inter-operate with each other with help of Constrained Application protocol.

A healthcare system based on IoT and fog is proposed [12] that is able to identify and control the outbreak of CHV (Chickungunya Virus). To diagnose possibly infected people, generate diagnostic or emergency alerts from fog layer, Fuzzy-C Means is used. For representing state of outbreak of CHV, Social Network Analysis is used. For risk-prone (infected regions), warning alerts are issued to healthcare agencies and government. A scheme is proposed [13] for dynamically selecting radio protocols for wearable IoT-based healthcare system that is energy-constrained. Patient's physiological parameters are transmitted using multiple radio protocols to the server using LPU (Local Processing Unit). For patient's continuous monitoring, an algorithm is developed [14] for real-time wearable device for analyzing ECG that uses Discrete Wavelet Transform and Support Vector Machine classifier that yields accuracy of 98.9%. A prototype for mobile real-time heart monitoring system is described [15] to access the patient's status (preventive or detective control) who had been prognoses for heart diseases. This system comprises mobile wearable devices which are capable of sensing cardiac rhythm. These devices are also able to access patient's geographical location.

Researchers proposed design and implementation for IoT-based healthcare system using personal health device- ISO/IEEE11073PHD and Constrained Application protocol standards which reduces data-loss and also enhances inter-operability [16]. A smart fitness mirror [17] provides a platform to users for monitoring health and fitness status every day. Body Mass Index (BMI) is monitored and the amount of

body-fat in user's body can also be monitored with help of sensors. The system also comprises ultrasonic sensor for measuring user's height and load sensors to measure user's weight. Total body water, lean body mass, and percentage of body fat can also be measured with help of electrode plates. A fog-driven IoT-based healthcare system is investigated, that focuses on key agreement and authentication. From the bilinear pairings, a three-party authenticated agreement protocol is proposed. The proposed protocol performs superior to Hamid et al.'s protocol [18]. Another secure key agreement scheme is proposed whose security is illustrated by ProVerif (for security simulation), BAN logic and also informal security analysis that demonstrate that the proposed scheme can attain the well-known security requirements [19]. For efficient treatment, prognosis, patient monitoring, and maintaining records, a smart and secure framework is presented [20] which can assist in smart design of hospitals using Artificial Intelligence and IoT. Moreover, a multifaceted system uses IoT for integrating various network elements, sensors, actuators as well as various other healthcare equipments. A user-friendly system is demonstrated on the basis of miniaturized polymerase chain-reaction equipment that can serve as an essential tool for medical professionals for dealing with infectious diseases that can be identified either with help of ribonucleic acid or through DNA. The researchers have tested its capability for dengue fever virus. Results show that this device can be used as efficient tool for early prognosis of diseases or even pandemic outbreak [21].

A new IoT-based architecture is presented for healthcare applications that primarily focuses on principles of weak coupling and relies on message-oriented middleware that is improved using semantic representation of exchanged data. For validation of the proposed architecture, a prototype is designed for bedsore risk detection [22].

A secure system is proposed for medical IoT devices that use LMDS (Lamport Merkle Digital Signature), which authenticates IoT devices by constructing a "tree", wherein the leaves represent patient's medical data hash functions. Furthermore, the centralized health controller determines the root with help of Lamport Merkle Digital signature verification. The experimental results demonstrate the proposed technique to be more secure and are able to identify malicious activities with low Computational Time and overhead [23]. A messaging system is presented [24] for an IoT healthcare service that uses Constraint Application Protocol and Message-Queuing Telemetry Transport (MQTT)-based system. This system is interoperable and based on international standards. In terms of round-trip time and transaction packets analysis, the system shows superior performance.

Assessing sleep quality is another vital research area in IoT, wherein detection and analysis of sleeping patterns is performed using Commercial off-the Shelf sensors and performs result prediction by using Random Forest model. The results demonstrate that this technique yields 95% accuracy to measure patients' sleeping patterns [25]. IoT-based user-friendly wheelchairs are proposed for providing self-supporting lifestyle for patients with impairments [26–28]. To monitor human activities and to interact with living environment, a home mobile healthcare IoT-based system is proposed [29] for patients using wheelchairs. The research focuses on architecture and design of WBSN (Wireless Body Sensor Networks).

The system can perform remote monitoring; the family members and wheelchair users can operate and perceive the intelligent equipments. For prognosis of Parkinson's disease, IoT-based systems have been proposed by researchers for monitoring and diagnosis of the disease [30–33]. A secure framework is proposed [34] using blockchain technology for healthcare multimedia data that helps to provide transparency and privacy among the intermediates as well as patients. This also ensures tracing of illegal activities during any phase of communication process.

To improve the performance of healthcare systems during pandemic, IoT Enabled healthcare systems solve medical challenges like price, speed, and complexity. The system can be customized to monitor calorie intake and treatment of diseases like diabetes, asthma, and arthritis [35]. The article[36] explores how IoT can support healthcare for enhancing healthcare services in better way. The paper [37] presents the detailed review on the application of machine learning techniques used for analysis of big data in the healthcare domain. This study provides an overview for doctors to keep themselves updated and well-informed with the latest trends in ML-based big data analytics for smart healthcare. Another important aspect in Healthcare and remote health monitoring is a systematic approach for security and privacy measures that should be used while monitoring the devices, and during communication, data storage and handling. The paper [38] studies the current situation of security and privacy of IoT-based healthcare systems and the challenges that are faced during implementation of security frameworks. The article [39] implements the Digital Twin (DT) framework for intelligent context-aware healthcare system. The results demonstrate that integration of DT with the medical field can improvise various healthcare processes and can provide an ecosystem that is scalable, comprehensive, and intelligent. The paper [40] proposes an IoMT-based health monitoring system that is able to monitor patient's real-time vital statistics, i.e., oxygen level, heart rate, pulse rate, body temperature, and communicates the live date to the doctors. Compared to existing health monitoring systems, this system achieved more than 90% accuracy. Moreover, it provides significant improvements in terms of accuracy, portability, and response time. Table 2 summarizes the various frameworks and approaches used with IoT in the domain of healthcare.

Thus, we can conclude that researchers are providing superior ways for monitoring and analyzing patient's health, thereby leading to global development of healthcare services. The growth of IoT in healthcare sector is tremendously evolving by connecting. Intelligent objects together and thereby allowing numerous applications to actively support the process of decision making for healthcare services. Although, there are some challenges that are associated with healthcare services that are presented in next section.

Table 2 Summary of various frameworks/approaches used in IoT-based healthcare systems

Author	Proposed work	Outcome
Wu et al. [5]	ECG monitoring system integrated on T-shirt	Low power ECG monitoring system with battery that can operate continuously for more than 110 h
Anuradha et al. [6]	Cancer prediction system	Secure system that encrypts patients' result to be stored on cloud that can be assessed by medical practitioners
Memom et al. [7]	Breast-cancer diagnosis system	99% classification accuracy for Wisconsin Breast Cancer
Abdulkareem et al. [8]	Model for diagnosing patients with COVID-19	Proposed model with SVM scored 95% accuracy
Palani er al. [9]	IoT-based predictive model for lung cancer	Provides a prediction model for effectual image segmentation
Han et al. [10]	Cancer rehabilitation scheme—Recommendation system	Able to extend patients' post-operative recurrence time by more than 95%
Catarinucci et al. [11]	Smart Healthcare—IoT aware architecture	For interoperation among various technologies, complex network infrastructure implemented
Sood et al. [12]	IoT-based healthcare system that identifies Chikungunya virus	Able to determine health severity, outbreak state with minimum delay in real-time notification generation
Misra et al. [13]	DROPS	Proposed scheme selects apt radio protocol that enhances data rate by 78% and throughput by 7%
Azaria et al. [14]	ECG analysis and classification algorithm	Yields accuracy of 98.9% using Discrete Wavelet Transform and Support Vector Machine classifier
Narvaez et al. [15]	Real-time mobile heart-rate monitoring system	Wearable devices which are capable of sensing cardiac rhythm
Ge et al. [16]	Design, implementation of IoT healthcare system comprising of Constrained Application Protocol and Personal Healthcare Device	Reduced data loss among devices and enhanced inter-operability

(continued)

Table 2 (continued)

Author	Proposed work	Outcome
Muneer et al. [17]	Smart Fitness Mirror	For measuring body temperature, the system yields 95.3% accuracy. For measuring body fat percentage, the system the system yields 93.7% accuracy and for body mass index, it yields 92.5% accuracy
Jia et al. [18]	Fog-driven IoT-based healthcare system	Provides security against common attacks
Wu et al. [19]	Authenticated Key agreement scheme	Secure key agreement scheme
Valanarasu et al. [20]	IOT and AI integration framework	Secure integration for Smart Hospital using AI and IoT
Zu et al. [21]	IoT PCR for pandemic disease detection	Vital tool to tackle outbreaks of infectious diseases identified by ribonucleic acid or DNA
Zgheib et al. [22]	New IoT-based architecture for healthcare applications	Prototype for bedsore risk detection based on Braden calculation
Alzubi et al. [23]	Blockchain-based authentication tool using Lamport Merkle Digital Signature	Provides authentication security with minimum Computational Time and overhead
Saleem et al. [25]	Sleep Quality Monitoring system	System projects patients' sleep into various classes with 95% accuracy
DSouza, Akash, Reddy et al. [26–29]	Smart Wheelchair	Provides movement controls, detects abnormalities
Romero, Alzubi, Anter et al. [30–33]	Parkinson disease	Model for detection and monitoring patients with the disease
Rathee et al. [34]	Multimedia data processing framework—IoT Healthcare using blockchain	86% accuracy
Nayyar et al. [40]	Working prototype-BioSenHealth 1.0	90% accuracy in comparison to existing health monitoring systems

4 Challenges and Future Directions in IoT-Based Healthcare

- Owing to the use of various sensors, central servers, and communication networks, IoT-based healthcare systems face many challenges. IoT-based wearable devices

are able to carry patients' sensitive and critical data. Thus, a significant issue in the IoT is security as these devices are vulnerable to attacks [41]. Another challenge is that data is received from millions of devices that require transmitting, storing, and monitoring in real-time and also requires high-speed computations and processing. As the data is received from multiple domains and different locations, data integration is also a challenge, especially for connecting it with existing medical systems [42].

- For elderly people, there exist concerns regarding usage of Smart devices that may require adequate training. Moreover, some wearable devices are uncomfortable for elder patients' body. Thus, more efforts must be laid in designing the devices that are more comfortable for patients, especially for elderly people.
- Moreover, there are much more areas in Machine Learning that can still be explored for developing IoT-based applications in healthcare for Disaster Management.
- The manufacturing of cost-effective Smart Healthcare Kits must be promoted that can be useful in epidemic or pandemic situations.

5 Conclusions

Growth in population imposes many challenges for the healthcare service providers and may lead to insufficiency of medical resources. These challenges must be carefully addressed, thereby providing efficient solutions based on available resources. To maintain an individual's well-being, proactive monitoring is imperative. There is an immense impact of IoT in the healthcare industry. IoT-based systems are able to provide intellectual and personalized healthcare benefits for better user experience. The key objective of this research paper is to investigate and explore various application areas and research activities that are involved in IoT-based medical systems This paper offers a methodical literature review of IoT applications in healthcare. Additionally, this paper presents the areas where IoT-based technologies can be explored.

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