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The Future of Healthcare: Using IoT for Personalized and Predictive Care

Ruturaj Ahire[1] | Aashitosh Pawar[1] | Ratna Chaudhari[2]

[1]Student, MSC (Computer Science), KRT Arts BH Commerce and AM Science (KTHM) College, Nashik, Maharashtra, India.
[2]Assistant Professor, Department of Computer Science, KRT Arts BH Commerce and AM Science (KTHM) College, Nashik, Maharashtra, India.

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Internet of Things, health care, services, applications, networks, architectures, platforms, security, technologies, challenges.

ABSTRACT

The Internet of Things (IoT) is essential for innovative applications such as smart cities, smart homes, education, healthcare, transportation, and defense operations. IoT applications are particularly beneficial for healthcare because they enable secure and real-time remote patient monitoring to improve the quality of people lives. This review paper explores the latest trends in healthcare monitoring systems by implementing the role of IoT. The work discusses the benefits of IoT-based healthcare systems with regard to their significance, and the benefits of IoT healthcare. We provide a systematic review of recent studies of IoT-based healthcare monitoring systems through literature review. The literature review compares various systems effectiveness, efficiency, data protection, privacy, security, and monitoring. The paper also explores wireless- and wearable-sensor based IoT monitoring systems and provides a classification of healthcare monitoring sensors. We also elaborate, in detail, on challenges and open issues regarding healthcare security privacy, and QoS. Finally, suggestions and recommendations for IoT healthcare applications are laid down at the end of the study along with future directions related to various recent technology trends

1. INTRODUCTION

The Internet of Things (IoT) is group of smart objects that is wirelessly connected via smart sensors. IoT will consist of billions of smart communicating things and is considered an integrated part of the future Internet. Recently, the IoT has drawn significant research attention in which it provides proper solutions for many modern applications such as waste management, smart cities, transportation, emergency services, security, retails, automotive industries, agriculture, and health

care [1].

Health care represents one of the most attractive applications that are enabled by the IoT. The IoT has the prospective to enhance many healthcare applications such as fitness programs, remote health monitoring, elderly care, and chronic diseases. Enriching the user experience, decreasing costs, and enhancing the quality of life are expected benefits of IoT-based healthcare service. IoT-based healthcare providers are expected to benefit by the reduction of device downtime through remote provision, the identification of optimal times for reloading supplies for diverse devices for their continuous operation and fairly distributing the restricted resources over the patient. In addition, IoT-based healthcare provides many benefits compared to conventional healthcare solutions, such as reliability, accessibility, and stability [3].

In recent years, the IoT in the healthcare domain has received broad attention from researchers across the world to detect the potential of utilizing the IoT in the healthcare and address its challenges. Accordingly, there are currently various applications, prototypes, and services in the field. Nevertheless, the use of IoT in the healthcare field still in its infancy. Thus, a comprehensive detail of existing research on the IoT-based healthcare is very helpful for a variety of researchers who are greatly concerned with conducting more research in this field. This chapter reviews current advances in IoT-based healthcare research and exposes different aspects such as security and privacy, network and communications, cloud computing and big data, e-health and m-health, system design and architecture, evolutionary, and fog computing.

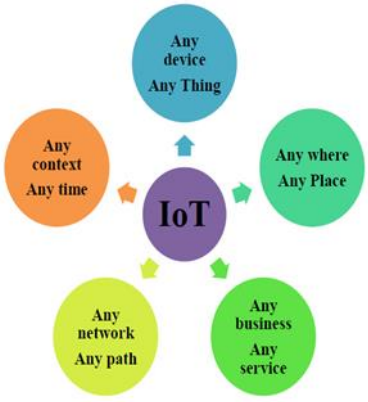

Figure 1. Overview of Internet of Things [1]

2. LITERATURE REVIEW

Healthcare is vast arena that are composed of many different components. Delivering healthcare involves clinical practices, hospitals, pharmacies, home health providers, long-term care providers, pharmaceutical companies, and medical-device manufacturers. It also involves health and wellness products and services, insurance companies, and governments providing services to end-users [4]. This section provides a review an analysis of the recent research on IoT-based healthcare monitoring systems. Table 1 summarizes some of the recent studies regarding IoT-based healthcare monitoring systems.

The wearable device developed by Wu, T.; Wu, F.; Qiu, C.; Redout J.M.; Yuce, M.R. A Rigid-Flex Wearable Health Monitoring Sensor Patch for IoT-Connected Healthcare Applications (2020) Presented monitors various physiological parameters, including body temperature (BT), electrocardiograph (ECG), and heart rate (HR). Using Pulse Arrival Time (PAT) to measure ECG and PPG, it is possible to estimate blood pressure (BP). The interaction between humans and remote monitoring programs is straightforward because all the components are designed within a rigid framework. In addition, the power consumption of the devices is low, and they can communicate wirelessly to take tailored measurements of a specific physiological signal. The physiological measurements can be wirelessly transmitted to a gateway using a BLE module. The data is encrypted at the sensor patch and gateways to maintain privacy, ensuring transmission security. The wearable sensor system is connected to the cloud using a smartphone and a Raspberry Pi module as a gateway; the data can be retrieved and analyzed from the cloud. Despite its low energy consumption, BLE technology is unsuitable for wireless communication over long distances and high data rates.

Islam, M.M.; Rahaman, A.; Islam, M.R. Development of smart healthcare monitoring system in IoT environment (2020) developed an intelligent monitoring system for use in a hospital. It not only collects data on patient BT, HR, and other vital signs but also monitors environmental factors in the hospital room, such as CO, CO2, and humidity. The success rate of modern healthcare systems is ~95% agreement between monitored and actual data in all cases. Medical staff can

view the data in real-time, either on-site or remotely. Hypothetically, the technology would be helpful during medical crises and epidemics, as medical personnel would have almost instant access to raw data. The prototype created is incredibly easy to design and use. Such devices could be helpful in managing infectious-disease outbreaks, such as COVID-19. Potentially, this system could save more lives by improving the efficiency of the existing healthcare system. However, at this stage, the system still lacks some epidemic-related sensors that need to be evaluated once implemented.

Hamim, M.; Paul, S.; Hoque, S.I.; Rahman, M.N.; Baqee, I. IoT Based Remote Health Monitoring System for Patients and Elderly People. (2019) presented an IoT-based healthcare monitoring system for patients and older adults based on an Android application. The sensors in this prototype collect BT, HR, and Galvanic Skin Response (GSR) data that is fed into a single system, the Arduino Uno platform. Raspberry Pi transfers the data to cloud storage. Android Studio was used to develop the Android app, in which health parameters collected from patients can be visualized. Doctors can use the application to prescribe necessary prescriptions and track the patient health over time.

An IoT-based real-time health-monitoring system can save a patient life by continuously monitoring the patient vital signs. The real-time health-monitoring solution proposed by Sangeetha Lakshmi et al. [8] continuously monitors patients wirelessly via a mobile app and GSM. Sensors capture vital signs that is transmitted to the cloud via Wi-Fi. The system consists of a data-acquisition module, a microcontroller (ESP32), and software. This system regularly measures and stores the patient BP, BT, ECG, HR, and SpO and transmits the data to the physician cell phone for alysis. The system also includes an alert system in which the physician cell phone receives a message when the patient vital signs are outside acceptable parameters. However, the system is only a prototype that still needs to be evaluated, tested, and calibrated.

Raj, J.S. A novel information processing in IoT based real time health care monitoring system (2020) introduced a novel information-processing system for IoT-based healthcare monitoring systems to manage big data in an IoT environment effectively. The entire data-processing process is divided into three stages: collection and aggregation, the classification and analysis of collected data, and decision-making. The experiments were conducted using Python. This model was experimentally verified in a simulation using different health sensors. The parameters were compared with existing hierarchical clustering and back propagation neural network models to validate the performance. This model leverages Apache Kafka and Hadoop to address the need for real-time data collection and offline processing. According to the authors of this study, the proposed method outperforms the more traditional hierarchical clustering model and the back propagation neural network model in data processing and information extraction; they claim that their proposed model achieves 97% accuracy.

A Wi-Fi-connected smartphone and an electronic wearable device are used by Jenifer, M.; Rinesh, S.; Thamaraiselvi, K. Internet of Things (IOT) based Patient health care Monitoring System using electronic gadget. (2020) to develop an IoT-based health-monitoring system. This system uses sensors to measure the patient physiological parameters, including HR, BT, BP, and SpO2. The patient data is collected via Wi-Fi from a remote location and stored on a cloud server, and the health parameters are continuously monitored. If abnormalities occur, an automatic alert is sent to medical professionals with the patient location. However, this study did not include experimental data or a comparative analysis.

3. METHODOLOGY

Access and Authentication

This section discusses the IoT-based healthcare techniques in terms of their privacy and security approaches. Chibelushi et al. argue that the IoT identification management (IDM) issues have been raised as an important concern when building an IoT system. Each thing (device and user) should have a unique identity, and the IDM should have the ability to differentiate between a user and a device, therefore, ensuring information and identity context safety. The paper studies the issue behind the IDM and introduces a new framework to examine the identity of Things. The proposed framework is embedded inside mobile ad hoc network and designed to serve wireless devices only in mobile. The proposed technique considers the limitation of network bandwidth by exchanging little information

at the same time. For security purposes, a sandboxing technique is used to protect the user data when device is shared with others.

Gope and Hwang proposed a new technology that uses a body sensor network (BSN) to protect the privacy of the user. As users may be vulnerable to privacy violations in case, they are not considering the security requirements; the paper highlights the major security requirements that should be considered in BSN. The proposed system consists of wearable sensors (i.e., electromyography (EMG), electrocardiogram (ECG), electroencephalography (EEG), and blood pressure (BP)[12]. The main function of the previous sensors is to gather the data and send it into a local processing unit (LPU), which works as a coordinator. The LPU can be a smart phone, a PDA, or any other portable device. The main function of the LPU is to work as a router between the server and the BSN by wireless communication medium (i.e., mobile networks GBRS/CDMA/3G). In case the LPU observes any abnormal behavior, thereafter it will send an alert to the patient who is wearing the sensors.

Compression and Encryption

The proposed system handles the key exchange using elliptic curve cryptography (ECC). The ECC composed of three stages: setup, regeneration, verification, and key exchange. The proposed system identifies the patient using patient SIM card number along with the private key. In order to avoid the replay attack, the private key is created for legal use without using third party [2].

Kumar and Gandhi proposed an authentication method by using hash functions, agents, session keys, and random numbers to validate devices using public key algorithms and a combination of hash and encryption. Furthermore, they proposed an authentication scheme to validate the IoT healthcare system device groups. They authenticate devices using five key steps of mutual authentication session [14].

Another hashing method is proposed in this paper, called transport layer security (TLS) protocol, to move the records from source to destination in more secure and reliable pattern. The proposed protocol helps the user to avoid lost messages. Datagram transport layer security (DTLS) is also proposed to tolerate unreliability. The DTLS is composed of a base protocol, handshake protocol, record layer, cipher layer, and alert protocol. The ability of an attacker to send multi-messages, which causes a Denial-Of-Service (DOS) attack toward the server, is the main challenge for this protocol. To overcome this concern, a smart authentication gateway to protect the sensitive data from both the attacker and malicious is proposed.

Table 1. Comparative study of various security techniques

Security Technique	Description	Strengths	Weaknesses	Use Cases
Encryption (AES, RSA, ECC)	Converts data into unreadable format to prevent unauthorized access	Strong protection of data. Widely used. Scalable.	High resource consumption. Complex key management	Data transmission Secure storage
Authentication Mechanisms	Validates identities of users/devic (passwords,biometrics, digital certs)	Prevents unauthorized accessmulti-factor increases security	Can be bypassed if poorly implemented	Device onboarding. User access control
Blockchain Based Security	Uses distributed ledger for secure, transparent, and tamper-resistant records	Decentralization Tamper. proof records	High energy and computational cost. Not real-time friendly	Supply chain tracking. Secure firmware updates
Access Control Mechanisms	Restrict user/device access based on policies (RBAC, ABAC)	Fine-grained control. Easy to audit	Complex policy design.Needs regular updates.	Smart cities. Home automation systems.
Physical Security Techniques	Tamper-proof hardware, secure enclosures, hardware-based keys	Protects from physical access attacks. Can complement software techniques	Costly to implement. Not feasible for all devices	Military devices. Medical IoT.

E-health and M-health

Electronic health (e-health) and mobile health (m-health) are recent healthcare practices that growing rapidly due to the spread of IoT healthcare devices. The massive

amount of health data that collected through IoT healthcare devices drags the attention of researchers to utilize these data in order to improve healthcare service. This section discusses the methods that focus on improving e-healthcare and -healthcare including aging, framework, system, model, platform, gateway, heart, and medicine.

a) Framework System Model and Platform

speeding up the growth of healthcare data leading to a massive amount of data that requires high-quality framework in order to manage and analyze such amount of data to provide high-quality healthcare services. This section discusses the proposed frameworks, models, systems, and platforms that aim to utilize IoT devices to improve healthcare services quality.

Presented a mobile gateway architecture for u-healthcare as well as provides a general idea of IoT in terms of u-healthcare applications. The proposed framework utilizes the heterogeneous data collected from various IoT devices in order to improve u-healthcare services. The presented work opens new path for researchers to utilize IoT sources to solve u-healthcare challenges.

A smart healthcare kit proposed by Gupta et al. [17] to monitor emergency medical services. The proposed model utilizes patient data that was collected from various IoT devices in order to aid emergency medical services with useful information. The proposed design considered as a health manager in which the system could replace the doctor by checking patient status and giving alarms if the patient health is at risk.

Another healthcare model is proposed by Lee and Ouyang in order to utilize the data collected from personal health devices of IoT. The proposed model presents collaboration protocols, which detect risky information and share it among other devices. The proposed model aims to improve the quality of personal health feedback by increasing and utilizing the collaboration between IoT devices.[18]

b) Aging

New technologies have contributed directly to improving population aging in the last decades. As IoT devices become widely used, IoT drags researchers? interest in utilizing the huge amount of information that is captured and collected using these devices. Konstantinidis et al. [15] presented a new idea that aims to utilize the huge amount of data collected by IoT devices in order to assist active aging as well. The proposed method employs IoT healthcare devices with the aid of IoT-oriented infrastructures such as extensible messaging and presence protocol (XMPP). The proposed platform provides a disease management tool.

Table 2. Comparative study of various e-health and m-health technique

Aspect	e-Health	m-health
Framework	Centralized, institution-based systems (e.g., HIS, EHR, EMR)	Decentralized, app-driven platforms using mobile OS frameworks (iOS, Android)
Gateway	Typically involves hospital/clinic-based gateways (middleware, servers) for secure data routing	Mobile gateways such as smartphones, tablets, or Bluetooth hubs that connect to wearable devices
Heart Monitoring	Integrated in clinical settings with ECG machines, cloud-based analysis	Real-time monitoring via smart watches (e.g., Apple Watch, Fitbit), Bluetooth heart sensors
Medicine Management	Automated dispensing systems, hospital pharmacy integration	Reminder apps, SMS alerts, barcode scanning for medication tracking
Age Group Targeting	Older adults and professionals (complex interfaces, structured systems)	Broad usability, especially among youth and middle-aged populations (user-friendly mobile apps)

Big Data and Cloud Computing

The spread of IoT healthcare devices contributes directly to increasing the amount of collected healthcare data. This increment in healthcare data drags the attention of researchers to utilize computational capabilities in order to support doctor decisions by inferring useful information about patient's health, which reduces the burden on doctor's side. This section targets the methods that focus on utilizing the large amount of healthcare data in order to improve healthcare services.

a) Medical Emergency Decision Support Systems

Supporting doctor decision in emergency cases using computers has become necessity as medical data massively grows because of the spread of medical sensors that tied to patients. This section discusses the decision support methods that utilize the collected data

from IoT devices in order to take proper actions accordingly. Rathore et al. [19] proposed management system for medical emergency using Hadoop in order to utilize and manage massive amount of heterogeneous data that are collected through IoT devices. The proposed management system employs enhanced network architecture to collect the data; then, an intelligent system is used to analyze the data and take the proper actions. The proposed system is supposed to collect data from a huge number of sensors that are attached to human body in order to improve the quality of healthcare services. In addition, Rathore et al. [20] presented a real-time emergency system to utilize IoT healthcare devices to public health using the medical sensors that are attached to human bodies. The proposed system consists of multiple layers starting with data collection and ending with intelligent building layer, which handles data analysis decision making. The purpose of such systems is to utilize and manage the huge amount of heterogeneous data collected from diverse healthcare sensors.

Fog and Cloud Computing

Fog and cloud systems are essentially incorporated into IoT healthcare domain. The data gathered from IoT-medical devices is allocated to fog and cloud systems for storing, analysis, prediction, and other processing operations. The processed data is then delivered to users who have the privilege to access it.

Table 3. Comparative study of different computing techniques

Computing Technique	**Definition**	**Architecture**	**Advantages**	**Limitations**
Cloud Computing	Delivery of computing services over the internet on demand	Centralized (data centers, cloud providers)	- Scalable - Cost-efficient - Accessible globally	- High latency - Privacy concerns - Internet-dependent
Edge Computing	Processes data near the source (devices or sensors)	Decentralized (closer to the data source)	- Low latency - Real-time response - Bandwidth optimization	- Limited processing power - Management complexity
Fog Computing	Extension of cloud to the edge; intermediate layer between edge and cloud	Distributed (fog nodes near edge devices)	- Better latency than cloud - More scalable than edge alone	- Still evolving - Complex infrastructure

Network And Communication

This section includes three main subsections, namely 1. data handling techniques, 2. energy consumption which argues the possibilities of improving the consumption rate, decreasing overall delay, and enhancing the overall reliability; the last section named 3. combined techniques which apply various approaches to manipulating health data measurements from collecting data, sending, storing, and analyzing stages.

Table 4. Comparative study of different networks and communication techniques

Networksand communication techniques	**Type**	**Speed**	**Range**	**Reliability**
Ethernet (LAN)	Wired	100 Mbps – 10 Gbps	Up to 100 m (standard)	Very High
Wi-Fi (WLAN)	Wireless	150 Mbps – 1.2 Gbps (Wi-Fi 6)	Up to 100 m indoors	High
Bluetooth	Wireless	Up to 2 Mbps	10–100 m	Medium
Zigbee	Wireless	20–250 Kbps	10–100 m	Medium
Optical Fiber	Wired	Up to 1 Tbps (theoretical)	10–80 km (without repeaters)	High

4. SYSTEM DESIGN AND ARCHITECTURE

ELECTROCARDIOGRAM

Electrocardiogram (ECG) is the procedure of tracking and preserving the electrical activity of the heart by employing the electrodes placed on the specific areas of

the patient body. Huge data is expected to be generated from this process. Gupta et al. [21] stored and displayed this data on a website and made it available to the authorized personnel. The authors used Raspberry Pi that is a substantive, inexpensive, and has much scope for future.

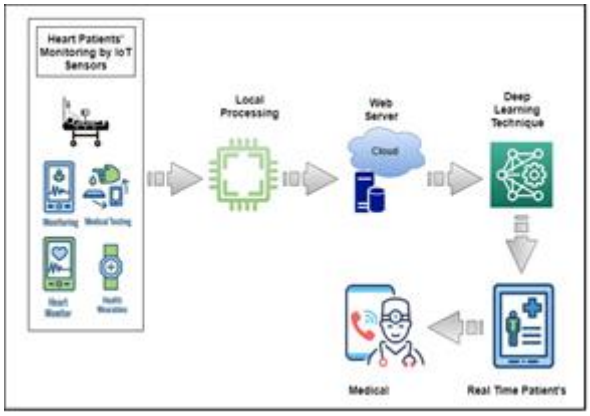

Figure 2. Architecture of ECG monitoring system [2]

MONITORING

There are many cases in which patients need long-term monitoring such as patients with chronic diseases. Hence, the provision of constant monitoring is necessary. This section shows some IoT projects that focus on this issue. For example, Anumala and Busetty [22] classify smart devices as health devices like a micro-oven. They extracted a significant amount of data from the smart devices for monitor the health status of a patient. The working principle of the smart devices is to store and manage the health information.

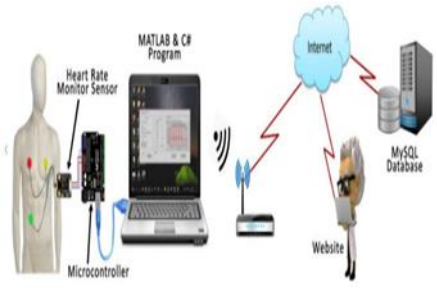

Figure 3. Architecture of the ECG Monitoring System

Figure 3. Health monitoring system for Patient [4]

MOBILE APPLICATIONS

Mobile applications have paved way for digital revolution in the healthcare industry by enabling healthcare professionals to quickly cater to medical emergencies and provide improved patient services.

SENSOR TECHNOLOGY

The sensors are small devices that are used to detect data (heat, moisture, light, motion, etc.) from the physical environment and convert it to readable data using an instrument or an observer.

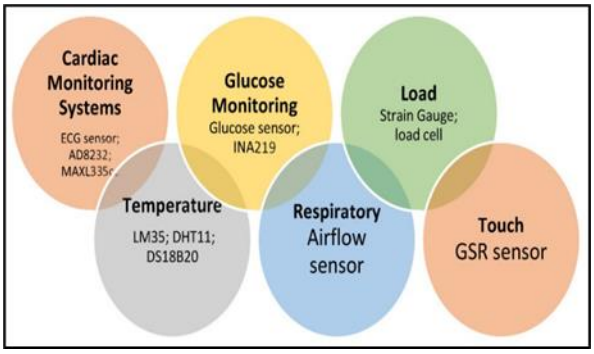

Figure 4. IoT sensors for healthcare monitoring [5]

WEARABLE DEVICE

The use of wearable healthcare devices through the IoT is the best way for long-term medical care because it allows patients to get their health information. In addition, for the patient health, it is necessary to monitor the environmental criteria that affect the health. Additionally, it is easy to use for elderly patients.

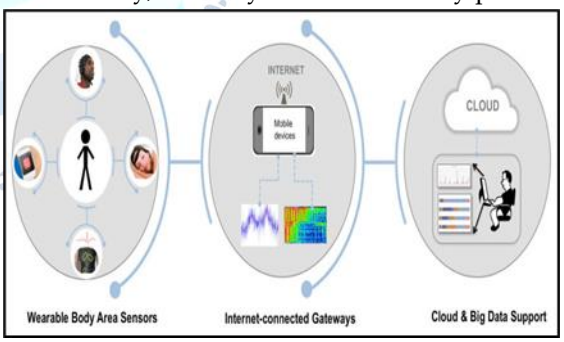

Figure 5. Architectural elements of wearable device [23]

5. APPLICATION OF HEALTHCARE

CHILDREN HEALTH INFORMATION (CHI) :

Children emotional, behavioral, and physical health needs are the main focus of Children Health Information (CHI). It assists carers, educators, and parents in keeping an eye on children diet, mental health, and general wellbeing. With adult assistance, CHI services encourage kids to learn about healthy eating and other health-related topics.

TELE-HEALTH :

Through the use of gadgets like computers or smartphones, telehealth enables patients to obtain medical services from a distance. Medical devices gather patient data, which is then sent to physicians for analysis and long-term health monitoring. With apps that use smart watches to track heart rate, calories, and other health metrics, this service is becoming more and more well-known. Numerous researchers are trying to make telehealth better.

HEALTH MONITORING APPLICATIONS:

IoT is used in many applications to track a patient health in real time. Heart rate, body temperature, blood pressure, oxygen levels, blood glucose, ECG signals, and more can all be monitored with these apps. The system notifies medical professionals when an anomaly is found. These tools assist physicians in monitoring patients' health and providing essential medical care. Similar features are shared by the majority of these applications: they gather, store, and transmit health data for possible problem analysis. But they also have comparable difficulties in guaranteeing precision and dependability.

6. MAJOR CHALLENGES IN HEALTH MONITORING SYSTEM

SECURITY AND PRIVACY

Security is essential when using wireless technology in health monitoring systems in order to preserve patient privacy. Patient data is at risk in the absence of adequate security. Systems for monitoring health must make sure:

a) Availability: Information will be available when required.

b) Integrity: Information shouldn't be altered.

c) Confidentiality: Patient information must be kept confidential.

d) Access Control: Data should only be accessible by those who are authorised.

Health monitoring system security is comparable to that of ordinary networks, and patient data should be protected from cyberattacks using cryptographic techniques.

POWER CONSUMPTION

Another significant issue with health monitoring systems is energy consumption. Low-power devices and communication protocols will save energy and last longer. To make the system more energy-efficient, the power consumption of the numerous biosensors and devices used by these systems must be carefully considered. It difficult to create IoT devices that use less energy.

STORAGE CAPACITY

IoT devices generate a lot of health data, and storage space can be limited. Even though storage is increasing, it's important to store large amounts of data in smaller spaces. Data compression (either lossy or lossless) can help, but in healthcare, lossless compression is preferred because medical data is highly sensitive, and even small changes could cause significant problems.

DATA PROTECTION

It crucial to prevent unwanted access to health data. To guarantee that only authorized users can access the data, robust security measures must be in place. Physical device security, safe data routing, safeguarding sizable datasets, and maintaining data handling transparency are among the difficulties.

7. BENEFITS OF USING IOT IN HEALTHCARE:

The IoT will reshape healthcare as we know it, with profound implications. In terms of how apps, devices, and people communicate with each other to deliver healthcare solutions, we have reached a whole new level of evolution. The IoT has given us a new perspective and tools for an integrated healthcare network, greatly improving healthcare quality.

The IoT has made it possible to automate healthcare procedures that previously required a significant amount of time and left room for error due to human involvement. For example, to control airflow and temperature in operating rooms, many hospitals now use networked devices.

Although there are countless ways that the Internet of Things can enhance healthcare, the following are some of the main advantages:

1. Reduced cost of care.
2. Human errors are reduced.
3. Elimination of the limitations of distance.
4. Reduced amounts of paperwork and record keeping

5. Chronic diseases are detected early.
6. Improvements in medication management.
7. The need for prompt medical care.
8. Better treatment outcomes.

8. CONCLUSION

In this article, IoT was defined as main distributor of health care systems as one of IoT most important uses. Helps to better provide people with healthcare at any time in any region by eliminating geography, time and other barriers while increasing coverage and efficiency at the same time. The IoT health revolution is a reality and thus fair, affordable care provides high-quality care to people. These applications produce large quantities of sensor data to be handled properly for monitoring and handling. Cloud computing, through its Base, is a promising approach for efficient knowledge processing in the health sector. The framework provided is unique and can be used to handle cloud device and network data specific to a patient. Built on IoT and its design principles, the cloud app allows for direct communication with sensor devices while at the same time making it versatile and effective to serve stored data, users and sensors. Wireless sensor networking in which single access is provided to embedded sensor control systems and the complete system service. This paper aims to lead to a fully integrated IoT-based healthcare system and acknowledges the need to integrate the various IoT services further. Further work on safety issues in relation to the different implementation phases needs to be completed.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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