Internet of Things (IoT) for Secure and Sustainable Healthcare Intelligence: Analysis and Challenges

Sunday Adeola Ajagbe[1(✉)], Sanjay Misra[2], Oluwaseyi F. Afe[3], and Kikelomo I. Okesola[3]

[1] Department of Computer Engineering, Ladoke Akintola University of Technology, LAUTECH, Ogbomoso, Nigeria
saajagbe@pgschool.lautech.edu.ng
[2] Østfold University College, Halden, Norway
sanjay.misra@hiof.no
[3] Department of Computer Science, Lead City University, Ibadan, Nigeria
{afe.seyi,okesola.kikelomo}@lcu.edu.ng

Abstract. Many medical errors are caused by inadequate critical patient-related medical data. The use of information and communication technologies (ICTs) has the potential to improve medical data accessibility, and it is critical for patient safety. Meanwhile, the introduction of computing technologies that are IoT-enabled on data will result in significant changes in the healthcare environment. There is an emerging large and multifaceted architecture of technology and applications for ubiquitous computing. Mobile phones, laptops, Wi-Fi, Bluetooth, and a variety of digital, Radio Frequency Identification (RFID), wireless sensor network (WSN) technologies, and other sensing devices are now widely used in the healthcare industry as parts of artificial intelligence contributions to healthcare. This paper is aimed at analyzing the IoT for Secure and Sustainable Healthcare Intelligence with a view to exposing the IoT exploration of smart health. The paper described IoT-enabled technologies, IoT applications for intelligent healthcare, the effects of IoT on quality and affordable healthcare delivery, secured IoT for healthcare error reduction and optimization, and research trends. We concluded the paper and highlight the problems in making IoT a reality as future work.

Keywords: Artificial intelligence · Healthcare intelligence · Internet of things IoT · Internet-enabled system · Internet of medical things · Security

1 Introduction

The internet of things (IoT) is a special type of network that is based on the connectivity that exists among sensor-based devices and Radio Frequency Identification (RFID) such that a ubiquitous sensing environment is created in a way that a complete solution is provided [1, 2]. The first time the term "IoT" was coined was in 1999 by Kevin Ashton

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[3]. Analyzing each term in this concept will lead to a better understanding of what the IoT is all about. Internet is defined as a globally interconnected communication of computer networks over a communication bandwidth. While "Things" refers to any physical (machines, objects, animals, humans) or virtual (business procedures) that can be made intelligent by providing a means of unique identification, connectivity to the internet, and passing data over a network without human interference [4].

Data format generated from these varying sensors differs depending on the type of device and targeted mode of processing for specific analysis. Basically, IoT technology functions based on the information supplied by sensors on devices. It converts electrical signals from these sensors into mechanical parameters such as pressure, motion, temperature, and others. The ability to make meaning out of these signals without human interference is what is being regarded as intelligence in this discourse. Internet of things has brought a dynamic change to the internet environment in a way that has generated a novel community referred to as a smart environment in which the vast volume of generated data can be accessed and processed for automated utilization [5]. Virtually every aspect of human life has been revolutionized through the impact of IoT, ranging from home to work environment, industries, governance, healthcare delivery, and others [6]. The general goal of IoT is to provide services that can enhance and improve the human way of life, by making connectivity available anytime with anything, anywhere over any network [7]. IoT functionalities are achievable due to the availability of cloud computing services, and this makes many services intelligence-based [8].

IoT has wide application areas as its embraces the integration of other emerging technologies, which are described in this paper as IoT-enabling technologies. This has resulted in IoT being deployed in automation, home automation and monitoring, heavy machinery, factories, transportation, electricity, energy, smart cities, and appliances such as television, and smartphones just to mention a few, as the list is endless [9, 10]. The major application area of IoT is depicted in Fig. 1. The focus of this paper is to;

i. Analyse IoT-enabled technologies with respect to sustainable healthcare;
ii. Discuss IoT applications for intelligence healthcare;
iii. Enumerate sustainable IoT techniques for error reduction, optimizations and challenges (security) in healthcare intelligence delivery

This paper has the basic element of the IoT environment in Sect. 2, IoT application for intelligence healthcare in Sect. 3, sustainable IoT techniques for error reduction, optimizations and challenges (security) in healthcare intelligence delivery 4 and conclusion and future suggestion in Sect. 5.

2 Basic Elements of IoT Environment

The six basic elements required to provide IoT functionalities as itemized by [11] are identifiers, sensing devices, communication devices, compute devices, services IoT and semantics. These elements are responsible for the six fundamental operations involved in IoT actualization, which are identification, sensing, communication, computation,

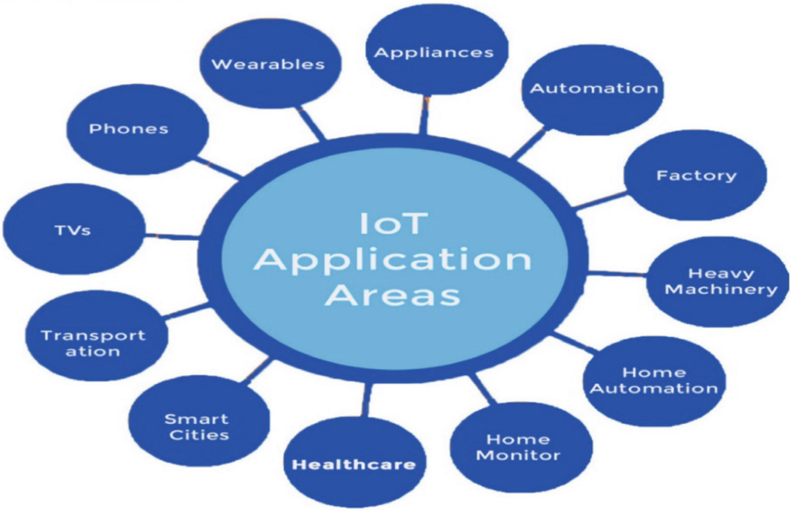

Fig. 1. Application areas of IoT

services and semantics. This section will explore details of the basic elements of IoT from the perspective of the six itemized fundamental operations.

Identification
There is an explicit identification for each object within the IoT network. There are two procedures in identification: naming and addressing. The naming refers to the object's title or name, while the addressing clarifies the object's location or address within the network. These two processes are completely different; even though two or more objects may have the same name, yet every object is within the IoT network is distinct. A number of ways of speeding up the naming of IoT network objects have been identified [12]. Initially, Internet Protocol version 4 called IPv4 was used to allocate the address, but it was impossible to meet the demand due to a large number of IoT devices; nevertheless, IPv6 is widely used today because it uses a 128-bit addressing system. Every object in IPv6 has its own unique address, which makes every object on the IoT network distinct.

Sensing
This IoT operation entails gathering data from the environment through the use of IoT sensing devices and sending it to a local or cloud-based database. Intelligent and portable sensors and actuators can all be identified. The information gathered is sent to the storage medium. RFID tags, portable sensors, smart sensors, wearable, actuators and other detection devices are used to gather data on objects [13].

Communication and Computation
Communication is one of the key purposes of the IoT, in which diverse devices connect and communicate with one another. Communication devices can send and receive messages, documents, and other data over the communication layer. IoT communication techniques communicate heterogeneous artefacts to achieve smart services. Further

explanation of communication technologies of IoT is entailed in under Technologies Enabling of IoT in the next section [14]. Sensors are used to compute the information acquired by the objects. It is utilized to create processing for Internet of Things (IoT) applications. Hardware platforms such as Arduino, Raspberry Pi, and Gadgeteer are used, while Android, Tiny OS [15], Lite OS and Riot OS are some of the operating systems that are used [16]. The operating system is crucial in the processing of software platforms that can ensure sustainable healthcare delivery in an IoT environment.

Services IoT
There are four types of services provided by applications [17, 18], which are identity service or identification service, aggregation service, collaborative service, and pervasive or ubiquitous service. The first service is linked to an object or a person's identification. It is utilized to figure out who sent the request and what the request is all about. The aggregation service gathers all the data about the objects and handles the processing accordingly. It can be referred to as the aggregation of information. The collaborative service makes judgments based on the data collected and sends appropriate responses to the devices. The pervasive service also known as ubiquitous service is used to replace equipment without regard for time or location. These are the four services carried out by IoT to actualize its functionalities in healthcare intelligence and every other field of its application.

Semantics
It is the IoT's goal to make it easier for users to complete their jobs. It is the most critical component of IoT in order to fulfil its tasks. It serves as the brain of the IoT. It takes in all of the data and makes the necessary decisions about how to respond to the devices or make inferences based on the data collected [11].

The IoT basic elements and their features that make IoT productive for healthcare intelligence are shown in Fig. 2.

Classification of IoT Technologies
The IoT technology application can be classified into three different categories by different authors [3, 19], the most mentioned categories are: healthcare delivery, smart cities, environmental, commercial, industrial, and general aspect. There are three known classes of IoT-enabled technologies in healthcare, namely identification, communication, and location technologies. These IoT-enabled applications in healthcare include Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA), and this is discussed in the next session. Figure 3 shows PRISMA Flow Chat HIoT-Enable Technologies in healthcare, it shows the interactions between healthcare IoT technologies, identification, communication, and location technologies.

i. **Identification Technologies**

To be useful, an IoT system must allow authorized nodes (sensors) to access patient data remotely. A healthcare network's node and sensor identification are required. In order to establish identification and enable clear data exchange, each authorized entity must be assigned a unique identifier (UID). A UID is associated with nearly every healthcare

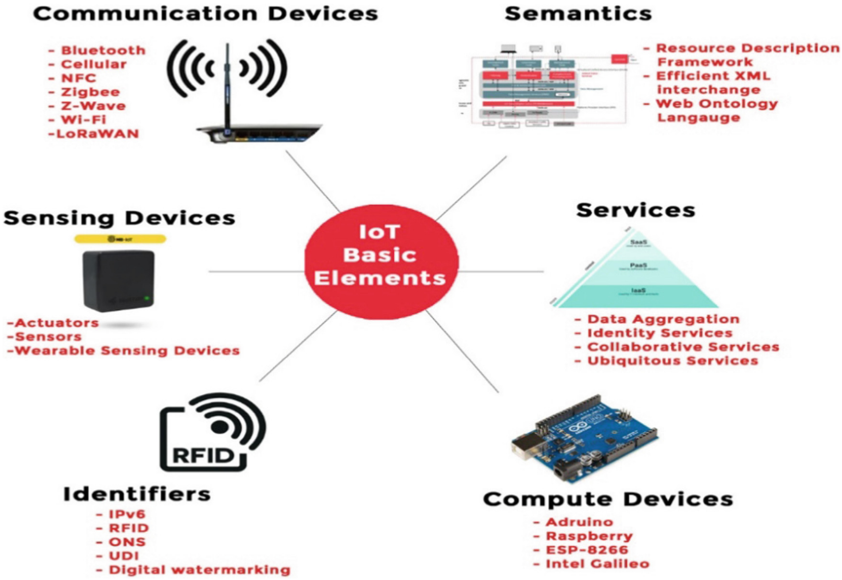

Fig. 2. Basic elements of IoT environment

resource (hospital, doctor, nurse, caregiver, medical device, etc.). This ensures digital resource identification and connectivity. The literature lists numerous identification standards. The open science framework (OSF) developed one of the identifiers (the universally unique identifier- UUID and a globally unique identifier- GUID), while the other is a GUID [20]. The UUID does not require centralized coordination. Identifying and addressing a healthcare network's sensors and actuators is critical to system performance. Because IoT-based technologies are constantly evolving, the component's unique identifier may change. The device/system must be able to update this information to maintain its integrity [21]. A possible explanation is that the change in configuration affects both the tracking of network components and the diagnosis of the change. A global directory search for efficient IoT service discovery is required using the UUID scheme.

ii. **Communication Technology**

In an IoT-based healthcare network, various devices can communicate with each other through the use of communication technologies. Short-range (within a limited range of some meters) communication, and medium-range communication (which supports long distance communication) are the two main categories of these technologies. For example, communication within a body area network uses a short-range communication protocol, while the base station can connect to a BAN's central node via medium-range communication protocols, such as Wi-Fi. Most healthcare IoT applications use short-range communication technology [21]. Wireless communication technologies such as RFID, Zigbee, and Wi-Fi are among the most commonly used. The IoT Communication

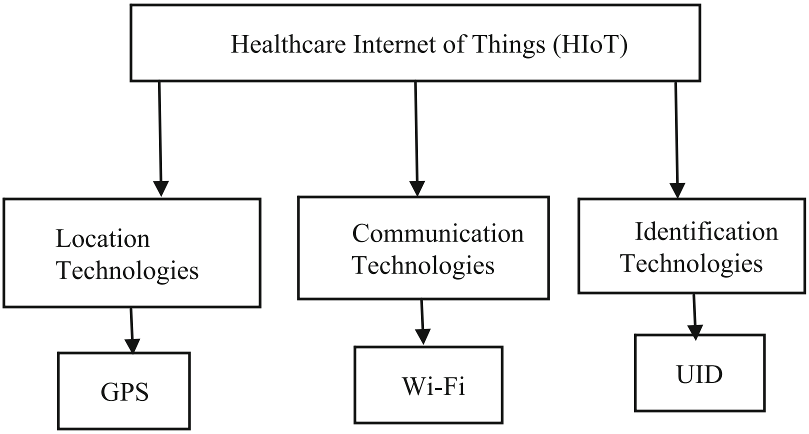

Fig. 3. PRISMA flow chat HIoT-enabled technologies

technologies include Wireless fidelity (Wi-Fi), WiMAX, Low-Rate Wireless PAN (LR-WPAN), Mobile communication, Bluetooth and WSN [22].

iii. **Location Technologies**

These technologies are used to track and identify an object's location within the healthcare network. Real-time location system technologies are employed, which track the treatment process based on resource distribution. Global Positioning System (GPS) is one of the most frequently used technologies in this category. It keeps an eye on things through the use of satellites. GPS can track an object's location as long as there is a clear line of sight between it and at least four satellites. This technology has a variety of applications in IoT-based healthcare delivery, including locating a patient's healthcare team or an ambulance. As a result, GPS's use in indoor applications is limited, as the surrounding infrastructure can act as a communication barrier. In these instances, a local positioning system network can be used effectively to track an object by deploying an array of receivers that detect the radio signal emitted by the traveling object [21]. Additionally, the local positioning system can be implemented via Zigbee, Wi-Fi, RFID, and other near-field communication technologies. Ultra-wideband (UWB) radio is preferred over conventional radios due to its superior temporal resolution. This method enables the determination of an accurate arrival time. Several authors have used UWB-based tracking systems that rely on the time difference of arrival. Future smart healthcare networks may include GPS and other high-bandwidth connection technologies [23].

3 IoT Applications for Healthcare Intelligence

The advancement in technology has been extended in recent times to the healthcare industry with the use of IoT-enabled devices. Social and technological advancements are combining to push the deployment of IoT in therapeutic settings. Health care costs are rising far faster than inflation as a result of the aging population in developed nations and the associated burden on clinical facilities [24]. Healthcare businesses are well-positioned to take advantage of the expanding availability of high-bandwidth connectivity, low-cost cloud storage and processing, and massive data analytics [25, 26]. This gives room to sophistication and improvement in several healthcare services and applications resulting in healthcare intelligence. Figure 4 is the general application of IoT in healthcare, it is all about monitoring and improving the health conditions of the patient.

IoT-based devices include wearable sensors, drug dispensers, remote monitoring, activity trackers, smart sensors, and the integration of smart medical devices. Because of recent technological advancements, it is now possible to diagnose numerous ailments and keep track of one's health with small, wearable gadgets like smartwatches [27], thereby transforming healthcare delivery from a hospital-centered system to patient-centered system. Examples include the ability to undertake clinical analyses (such as blood pressure and oxygen) without the assistance of a healthcare provider. Clinical data can also be transferred via high-speed telecommunications from remote sites to healthcare centers [28].

In conjunction with fast increasing technology (such as machine learning, wireless sensing, cloud computing, big data analysis, IoT, and mobile computing), the utilization of such communication services has made healthcare facilities more accessible [21] such that required medical and health data can be collected and the collected information is transferred to a physician or to a cloud platform using real-time monitoring through smart medical devices (e.g. smartphones, tablets, computers, and nearly anything else with a sensor) which are connected using the internet connectivity [29]. It serves as a decision-support system [30]. The IoT device captures and transmits health information such as oxygen, temperature, weight, blood pressure, blood sugar levels, pulse rate as well as Electrocardiogram (ECG). Currently, there are 20.35 billion connected devices which is predicted to hit 75.44 billion in 2025 globally [31].

The tremendous impact of IoT in the medical field has been ever-increasing due to advancements in smartphone technology, the transition from common sensors to intelligent sensors, and unequivocal progress made in software applications over the last few years. This undeniable impact of IoT is felt in the medical field to the extent that a new groundbreaking field emerged known as the internet of medical things (IoMT) [32].

3.1 Types of IoT Applications in Healthcare

With the trend of deployment of IoT technologies to healthcare delivery, there has been massive number of systems with varying capabilities [33]. Basically, the essence of these applications is to be able to introduce intelligence into the use of these devices, such that data gathered can be used in a way to sense impending health issues [34]. These systems can be grouped into two broad categories lone system and composite system and they could be in form of wearable devices, monitoring system, and drug dispenser [27, 34] grouped the wearable devices into 2 different classes: those used by medics and those that can be used individually without the assistance of the medics.

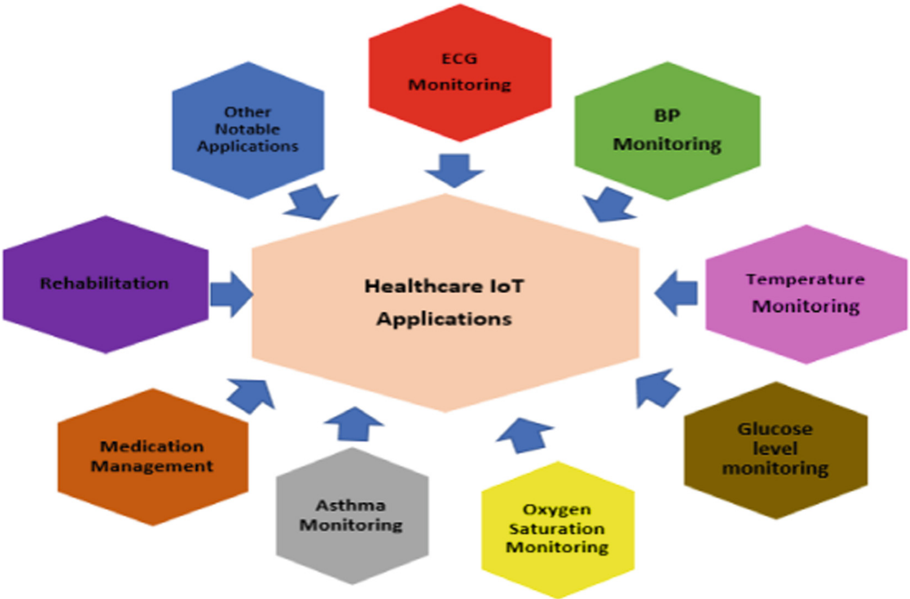

Fig. 4. IoT applications in healthcare delivery

i. **Lone System**

Systems in this category are those that focus on monitoring specific health situations by accepting singular input which is evaluated for generating output. Examples of this are glucose level monitoring, blood pressure monitoring, seizure monitoring, temperature monitoring, oxygen saturation monitoring, and electrocardiogram (ECG) monitoring, asthma monitoring [27, 35].

ii. **Composite System**

In this category, multiple sensor inputs are analysed to give a correct and adequate situation report of patient condition. In addition, communication is two-way such that the patient being monitored can have feedback based on the outcome of analysed sensor inputs data [21]. Rehabilitation systems, Medication management, wheelchair management, smartphone healthcare solutions, and Future IoT – embedded healthcare solutions are in this category [35]. Some of the systems in this category are discussed briefly in the next section. Basically, IoT can be applied to provide solutions to healthcare services. Some of these services include but are not limited to; Measurable (Quantitative) Healthcare, Preventive Care, Patient's Homecare and Monitoring, and Healthcare Data Management.

Measurable (Quantitative) Healthcare

IoT has increased human independence while simultaneously broadening the range of ways in which they can engage with their surroundings. A substantial part of the IoTs' contribution to global communication was made possible thanks to cutting-edge protocols and algorithms. It connects a vast number of items to the Internet, including wireless sensors, home appliances, and electrical devices. These devices can continuously measure and monitor a set of predetermined health status parameters being worn by the patient [36].

Preventive and Clinical Care

Patient-centered care and digital transformation in healthcare necessitate efficient clinical workflows, safer patient experiences, and improved preventative care. Distributed analytics can be used to gain meaningful insights from data of IoT devices generated by physician-patient encounters and wearables, which are generating vast amounts of data [37]. Medical technology has come a long way since the introduction of the first remedial treatment a decade ago. But the focus is now on preventing sickness through the use of IoT devices in healthcare settings. It boosts productivity efficiency. It enhances resource utilization. Continual monitoring of key physiological indicators is required for certain types of chronically unwell patients. In most cases, such individuals are admitted to hospital intensive care units (ICUs). This type of monitoring can be done utilizing sensors that collect full physiological information relevant to the different important body characteristics of patients, thanks to IoT-driven noninvasive monitoring technologies. The data obtained by these sensors is relayed to close family and caregivers via gateways and wireless networks, allowing them to take necessary action to care for the patient. [38]. This IoT technology takes the place of traditional in-person continuous monitoring by health care personnel and doctors in hospitals. Chronically ill people can receive better automated health care at home at a low cost with this technology. Other clinical care for patients in healthcare intelligence includes medication intake tracking, drug tracking, medical inventory and equipment tracking, smart hospital space and body position measurement.

Patient's Homecare and Monitoring

Using the IoT in healthcare delivery improves patient care by making it stronger, healthier, and more convenient. As a result of the IoT, doctors will spend less time travelling, diagnosing illnesses, and communicating with patients, allowing for a more efficient healthcare delivery system. Patients with chronic conditions, such as epilepsy, and those at risks, such as children and the "elderly," can be monitored remotely using IoT technologies and wearables without direct contact of the clinician with the patient [39, 40]. Wearable medical devices are those devices placed on the surface of the human body or in close contact with the human body. Environment-embedded devices make use of sensors embedded in strategic positions within the environment. Body position measurement, patient location, and overall monitoring of unwell patients in hospitals and at home are all possible applications of these healthcare devices.

Healthcare Data Management

Healthcare sensors that are powered by the IoT can be used for clinical exams and self-monitoring of one's own health. In the absence of direct contact with the patients, they assist remote clinicians in determining the best course of treatment for their patients [39, 40]. It is through the IoT that large volumes of data may be processed into actionable activities by connecting sensors and applying complicated rules and workflows. Also, the information gathered by these wearable sensors is stored in a distributed ledger indefinitely. They also keep track of the patient's progress, so that healthcare workers can see how the patient's condition changes over time [36] Patients' medical histories can be accessed while they are being tested, for example, using automated blood pressure, or digital thermometers [41].

4 Sustainable IoT Techniques for Error Reduction, and Challenges (Security) in Healthcare Delivery

In the United States alone, medical errors are a leading cause of death based on a study by researchers from Johns Hopkins, and these medical errors could be fatal. Examples of such include surgical complications that go unnoticed, as well as medication mix-ups and other data-related issues [42]. An incident to affirm this occurred in 2010 where a Singaporean couple, who conceived through in-vitro fertilization, were shocked when their baby was born with a skin tone that was obviously different from theirs as the parents, and it was also discovered that the baby's blood type differed from theirs. Undergoing a DNA test, it was confirmed that they were victims of a medical blunder. That is, the mother's eggs had been fertilized by a genetic specimen from a stranger. The specimens were handled by two embryologists who were found culpable of displaying lapses in procedure and human error. A solution to this problem is provided by the introduction of IoT which creates a world where components like sensors, barcodes, and RFID tags fixed to objects and linked to the internet give them a digital voice.

4.1 Healthcare Error Reduction Using Secured IoT Solutions

Wrong Blood Sample for Patients: Errors sometimes happen when blood samples are being taken in the wards. These human errors can be eliminated by utilizing IoT devices through scanning of patients' wristbands to validate their identity by nurses using IoT-enabled communication technology, and nurses can be directed through the blood collection process and print barcode labels using mobile printers attached to the sample [43]. Failure to Monitor Patient's Heart Rate: Heart attacks have claimed the lives of many people in recent years. When the heart's blood supply is cut off, a heart attack can ensue. Medical experts have found it difficult to save the lives of many people because of the lack of early diagnosis and detection of a heart attack, especially in developing nations. However, the advent of IoT solutions in healthcare with attention to error reduction has reduced this risk by monitoring the patient's heart rate [44].

4.2 Healthcare Optimization Using IoT

The Internet of Things (IoT) has the potential to spur the creation of smart systems that aid in the delivery of healthcare and biomedicine. The use of biomedical equipment in smart hospitals and the real-time monitoring of patient's physiological data can help diagnose clinical deterioration earlier, identify and track patients automatically, and track drug-patient correlations [45]. Errors happen when blood samples are taken in the wards. These human errors can be eliminated by utilizing IoT devices. Patients' wristbands can be scanned to validate their identity by nurses using these devices, and nurses can be directed through the blood collection process and print barcode labels using mobile printers attached to the sample using mobile printers [46].

4.3 Security Challenges in Healthcare Intelligence Delivery

Numerous benefits are attached to the deployment of IoT technology in the healthcare delivery sector. With these benefits arises the challenges that can entirely discourage the use of this novel technology. Basically, the challenges related to IoT-based healthcare delivery are general limitations of IoT technologies. Some of the challenges that have been identified in IoT applications and healthcare delivery inclusive are: Data management in terms of loss of privacy, system security, absence of stakeholder collaboration and interoperability. Security challenges that are related to IoT in general are also directly applicable and critical to IoT in healthcare, such as lack of access control/ privacy, software system susceptibility, infected programs affecting IoT network, entity recognition, android security challenge and lightweight cryptographic systems and security protocols [47]. Table 1 presents the analysis of these security challenges in intelligence healthcare delivery.

In the Table 1 present some IoT-based technologies with their limitation/challenges for an improved healthcare delivery.

Table 1. Healthcare IoT-based study, descriptions and challenges

S/N	References	Description	Challenges
1	[24]	Generation of applicable knowledge from multi-facetted/heterogeneous record by proposing the introduction of business analytics technique, i.e. (interoperability) Also, architectural reliability is address by proposing the implementation of a mess topology. While Network security and power consumption were addressed by implementing device- level authentication and link encryption	Encryption technique introduced to handle data confidentiality can hinder the system from accessing full potential of business analytics technique. The system has limited functionalities
2	[35]	A physical medication box enhanced with IoT technology to help individuals to stick to timely and correct usage of medication	Power consumption is high, hence faster power drainage. Needs enhanced security measure like second level authentication accessing the box. Also, needs more sensor to get more health details

(*continued*)

Table 1. (*continued*)

S/N	References	Description	Challenges
3	[34]	A monitoring model for epileptic patients using a cloud-based health IoT system was proposed. DWT-SVD based watermarking was applied on time-frequency domain EEG data to enhance data security	Further studies can be done on feature extraction and classification with watermark extraction from EEG data in the cloud, to detect or predict epileptic seizures in the patient. Other machine learning algorithms can also be used
4	[14]	This article highlights the description of the major aspects of wireless body area networks (WBAN)-based telemedicine such as research issues, characteristics, and its challenges in telemedicine systems for patient monitoring in different circumstances. The authors designed a framework to integrate BAN on telemedicine systems	The major challenges are bandwidth limitations, power consumption, and skin or tissue protection
5	[11]	The classification function of the wound by the monitoring system into three classes was based on the decision tree	Other health issues that could affect the healing rate of the wounds were not put into consideration, as well as the environment condition around the wound area
6	[48]	The paper presented a review of challenges faced in IoT-connected healthcare and information security in developing nations. The study began by providing an overview of IoT connectedness in healthcare in developing nations. An analysis of how this portends a threat to security was provided	The challenges of healthcare delivery in developing nations evolve security and corruption

5 Conclusion and Future Direction

This paper discusses the novelty of IoT in healthcare delivery, viz-a-viz IoT-enabled technologies, basic elements and classifications of IoT environment and technologies respectively. The IoT applications for healthcare intelligence were x-ray including medical image processing that was done with the help of AI tools. The effects of IoT on quality and affordable healthcare delivery. The penultimate section explains sustainable IoT techniques for error reduction, optimizations and security in healthcare intelligence delivery with a view to unveilling the challenging area of IoT technology in healthcare for possible qualitative healthcare delivery. The future direction in the area of secure and sustainable healthcare intelligence is to address the challenges of confidentiality, privacy, security and ensure a robust and healthcare intelligence system. This includes but is not limited to:

i. Address the issue of data anonymization, a desire for cryptography system protection and relational data concealment has arisen. The homomorphic encryption technique could be employed in research to find a suitable solution to the privacy concern and it is a liable tool for intelligence and sustainable healthcare delivery.
ii. Further studies are needed to address feature extraction and classification with watermark extraction from EEG data in the cloud, to detect or predict epileptic seizures in the patient. Other machine learning algorithms can also be used.
iii. The challenges of data security in the healthcare sector and corruption in funding healthcare section in the developing nation need to be addressed

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