



Internet of Things Technologies in Healthcare for People with Hearing Impairments

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Abstract. The Internet of Things (IoT) is a technology that connects physical objects, software, and hardware for interacting with each other and exchanging valuable data. In the healthcare sector, those data can be used by physicians, vendors, health organizations, and researchers to improve healthcare quality and reduce annual healthcare spending. Consequently, the emergence of the IoT in the healthcare field has led to transformative growth in activity and creativity. The rapid proliferation of IoT devices and applications can assist people of all ages with hearing difficulties in their daily activities to improve their and their caregivers' quality of life. People with disabilities, particularly those with hearing impairments, have fewer opportunities for social interactions, education, and access to modern technologies. These aspects are crucial factors in developing their learning capacity and cognitive skills. IoT technology can be oriented to assist people with hearing disabilities to enhance their quality of life without relying on assistance from others and that is a noble goal of our research.

Keywords: Internet of Things (IoT) · IoT in healthcare · Hearing Impairments · Wearable devices · security · privacy

1 Introduction

The Internet of Things (IoT) is a rapidly growing technology that connects hardware, software, physical objects/things, and computing devices for interacting, collecting, sending, and receiving data without human intervention [1]. These connected objects and devices join this sophisticated network with uniquely identifiable IP addresses. Most people think that the use of IoT applications and devices are only associated with smart homes and cities for users' comfort, privacy, and security. In fact, however, the development and growth of the IoT has opened up a new era in the healthcare, education, energy, transportation, and agricultural sectors as well as many other sectors [3]. By 2025, more than 75 billion IoT devices will join the Internet to provide significant computational resources and services for many different fields [2]. The emergence of the IoT in the healthcare field has led to transformative growth in activity and creativity. The rapid proliferation of IoT devices and applications can assist people of all ages with hearing difficulties in their daily activities to improve their and their caregivers' quality of life [4].

According to the World Health Organization, hearing loss affects more than 1.5 billion people worldwide, and by 2050 it is estimated that approximately 700 million people will be added to the number of those with disabling hearing loss. As a result, the rate of hearing impairments among the population has risen and is increasing the annual costs of the healthcare sectors of many countries [5]. This vast number of people with hearing deficiency or loss need assistance with using today’s technology. IoT technology should be oriented to assist people with hearing disabilities to enhance their quality of life without relying on assistance from others.

People with hearing sensory impairments cannot socialize effectively with ordinary people because they do not have one of the most important and frequently used senses [7]. Hearing sense strongly relates to speaking, and people who are affected with hearing impairments can be deterred from speaking or verbally communicating. To compare this condition to a computing device, if there are no inputs there will be no outputs, and so these individuals cannot gain any cognition or development from hearing. This can lead to mental disorders due to social isolation, frustration, and loneliness. Furthermore, students with hearing impairments have lower educational levels than ordinary students [6, 7]. The most effective way for people with hearing loss to communicate with one another is by using sign language. Sign language is the act of expressing oneself through hand gestures, eyes, face, lips, and body [12]. Similarly, normal people need to learn sign language to communicate with deaf people or use interpreters. In all cases, communication between deaf people must be live and visible to each other to convey messages and meaning. Many conditions can cause people to develop hearing disabilities. The most common cause of hearing loss is congenital and is present at birth due to genetic circumstances. The second most common factor that causes hearing loss is aging. Chronic middle ear infections and damage to the inner ear caused by ototoxic drugs or accidents are other causes of hearing loss [5]. The last condition of developing hearing disabilities is exposure to loud noise or loud music for a long time, which can damage the inner ear’s nerve [5].

Cochlear implants and hearing aids are important solutions for people who are suffering from hearing deficiency, as they allow them to improve their oral communication for language acquisition and enhance their sound awareness. There are four levels of

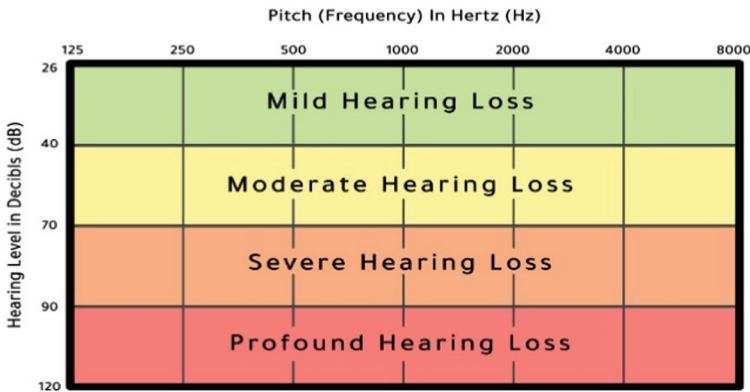


Fig. 1. Degrees of Hearing Loss

hearing loss as seen in Fig. 1: mild (26–40 dB), moderate (41–70 dB), severe (71–90 dB), and profound (above 91 dB) [13]. Indeed, many deaf people are not able to use either cochlear implants or hearing aids due to their level of hearing deficiency not being supported [10]. Additionally, many people who have had cochlear implants or use hearing aids are not satisfied with these solutions due to many reasons related to background noise, fit and comfort, the inferior quality of hearing and the risk of surgery failing [11].

2 The Internet of Things (IoT): An Overview

As previously mentioned, the IoT comprises different gadgets and devices that make up a network of constantly communicating items. Some examples of items that can be included within IoT-based technology are sensors, wearable devices, controllers, actuators, and laser scanners [1, 14]. When these items interact and communicate in a constant fashion, they form a spectrum that can best be described as a network. According to [15], “the Internet of Things is the concept of connecting any device (so long as it has an on/off switch) to the Internet and to other connected devices. The IoT is a giant network of connected things – all of which collect and share data about the way they are used and about the environment around them”. The items in the IoT can interact together even outside of human participation, though some components of the IoT may require human actions to perform certain specific functions [16].

Today, several applications of the IoT have contributed to improving the human experience. For instance, smart homes, offices, cities, smart farms, smart cars, smart industries, pollution and waste control, automated gates and garage doors, traffic monitoring, and management, energy-saving thermostats and humidity controllers, and last but not least smoke and fire alarms all have been enabled by the interaction of different technologies within IoT networks [15]. Other phenomena that have improved the human experience by using the IoT include wearable devices that can track and monitor users’ health and fitness [14, 17]. The majority of modern devices interact with the IoT in some way enabled by some form of IoT – in fact, due to the sheer range of IoT applications, they cannot all be listed, which only emphasizes the IoT’s importance for the contemporary human experience. The most important way the IoT contributes to different technological transformations is by allowing incompatible items to interact meaningfully. Traditional manufacturers of different technologies may deliberately make devices incompatible with others – this is a business model that ensures that only the accessories and parts of the manufacturer’s initial product can work with the product, thereby assuring their organization of otherwise peripheral sales [18]. The IoT reverses this conundrum by providing a platform through which different incompatible technologies are not only able to interact and communicate, but also to generate actionable insights as reported by [19]. By bringing different technologies together, the IoT allows the benefits of all the components to be realized at the applicable stage [19]. Alternatively, the IoT also allows the shortcomings and limitations of different technologies to be complemented by other more able components [19] (Fig. 2).

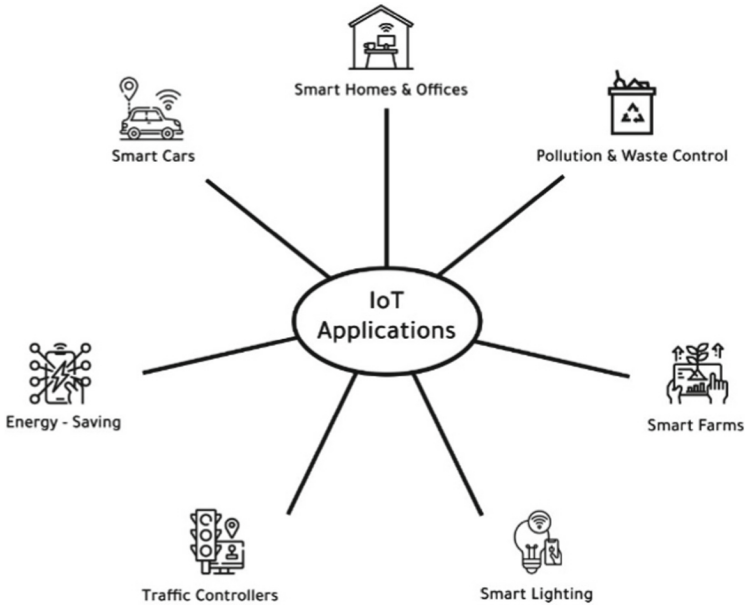


Fig. 2. IoT Applications

2.1 IoT in Healthcare

The IoT also has a vital role to play within the healthcare field. In healthcare, different components in the network can gather and integrate data before performing analyses [14]. Many applications within healthcare make use of the IoT – these range from diagnostic processes requiring the use of interactive devices, the collection of patient information, access to patient medical data, remote tracking of patient developments, and continuous monitoring [14]. According to [20], “The IoT promises many benefits to streamlining and enhancing health care delivery to proactively predict health issues and diagnose, treat, and monitor patients both in and out of the hospital”. All these applications contribute to the life-saving capacity of healthcare processes because they ensure the healthcare practitioner makes decisions that are guided by actual actionable knowledge. When analysis of data from different components on the network is achieved, the most valuable information can be gleaned and then used to promote evidence-based practice. [16] states that, “the Internet of Things (IoT) has been widely applied to interconnect available medical resources and provide reliable, effective, smart healthcare services”. It is possible to discern patterns, draw inferences, identify potential issues, and make appropriate recommendations when healthcare practitioners are equipped with credible information obtained from accredited healthcare technologies [14, 16]. For example, it is possible for a healthcare practitioner to determine whether patients are at an increased risk of developing certain conditions through monitoring their cholesterol levels – in this instance, the statistics regarding the patient’s cholesterol levels provide valuable and actionable information. Therefore, the IoT generates information and records that healthcare practitioners are able to use to ensure they reach desirable outcomes.

Within healthcare, the IoT enables the uninterrupted and constant collection of patient data. Most research opines that patient data become more credible and useful if gathered in a continuous stream instead of taking sporadic measurements [21]. This perspective is also held by [22], who postulates that uninterrupted information collection is crucial for the healthcare practitioner to reach meaningful conclusions. The IoT, by virtue of not requiring human intervention to function effectively, is able to ensure constant engagement by all its components as previously stated; once all the components are switched on, they continue to function for as long as they are able to acquire battery or some form of electric power [20]. Therefore, the IoT facilitates the uninterrupted collection of patient records, data, and information in a way that makes all resultant insights more credible than those collected outside of the IoT (Fig. 3).

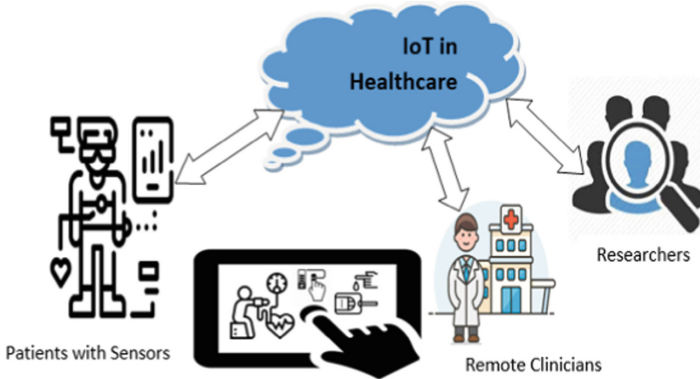


Fig. 3. The IoT in Healthcare

The focus of this survey paper is to outline and examine some IoT devices, applications, and systems utilized for people with hearing impairments as well as some obstacles and challenges that must be addressed. In fact, without reliable technology, people with hearing problems cannot communicate effectively with ordinary people unless they have certain communication abilities or technologies [9]. Therefore, we must ensure they have widespread access to modern technologies to satisfy their needs and concerns.

3 Related Work

Various research studies are available in the literature concentrating on how IoT technology interventions and development can provide the opportunity for people with disabilities, especially hearing impairments, to overcome traditional impediments. IoT technology solutions are used to facilitate their everyday activities and increase their social integration in daily life. IoT technology in healthcare has developed different applications and wearable devices that are used to manage hearing impairment complications as well as hearing loss in addition to increasing dependency on technologies as assistive tools. These devices and applications enable personalized healthcare, which can assist in remote monitoring, screening, diagnosis, and the early detection of hearing loss [1].

Wearable devices in particular have significant potential for use with speech recognition applications to assist people with hearing difficulties due to their lightweight and low cost [7]. Wearable devices with tangible interfaces are an alternative solution when it comes to mobility as auxiliary communication. [28] stated that using voice recognition to convert voice to text is an important implementation when communicating between ordinary people and deaf people without using sign language. The text data are transferred to Arduino over Bluetooth, where they are interpreted using ASCII characters and displayed on the wearable device as text.

People with hearing impairments cannot hear any sounds from the surrounding environment to improve their awareness. In this case, we cannot communicate or get their attention to raise the alert about dangerous situations unless we are visible to each other. In [8], the authors developed a wearable device that can sense and detect sounds in real-time such as a phone or bell ringing, alarm sounds, brake sounds, dogs barking, other sounds related to the audio fingerprint method and human sounds. When the wearable device detects and identifies one of these sounds, it directly transmits these data to the user through vibrations. Each of the above-listed sounds has distinct levels of vibration and intensity, which allows deaf people to easily distinguish between the various vibrations related to each sound. This system, [8] uses speech recognition methodology, but instead of translating spoken language into text, they translate sounds into vibrations in a wearable device. In addition, they use a microphone to process ambient sounds. Finally, for coding, they rely on Python programming language. Their system achieves an accuracy rate of 99% for identifying an alarm sound and a phone ringing, 98% for a doorbell ringing, 97% success in identifying a human voice, 96% success in identifying dog sounds and other sounds using the audio fingerprint method, and 93% success in identifying brake sounds. Those numbers are significant achievements for sound recognition and classification in real-time performance. In the end, [8] tried to enable and promote the use of IoT technology in healthcare with little equipment cost to protect people with hearing problems in an outdoor or indoor environment. In [12], the authors mentioned a smart bear for children that can sense and measure body temperature, blood pressure, oxygen levels, and heart rate. These vital data can be sent directly to the parents' smartphones via wireless communication technologies. The organization that invented the "Teddy the Guardian" smart bear can easily use their idea to address the hearing difficulties of deaf people and their caregivers. Many IoT applications and technologies are being developed to serve normal people. However, if manufacturers put more effort into orienting IoT technology to people with hearing impairments they could get many potential benefits and high profits.

Many researchers nowadays are focusing on how to facilitate communication between normal people and deaf people using today's technology. The work presented in [29–31] is a glove equipped with wireless communication technology and sensors that allows hearing-impaired people to interact with others who are not familiar with or do not understand American Sign Language. The job of the wireless glove is to sense and record the fingers flexion of the ASL and send the data to a smartphone programmed application using Bluetooth technology to convert the sign language received data into text and voice (Table 1).

Table 1. Summary of IoT Services for People with Hearing Impairments.

IoT services	IoT devices	Gateway	Communication type
29	Speech-to-text	Arduino	Bluetooth
8	Real-Time Detection	Raspberry Pi	USB
12	Smart bear	Mobile phone	Bluetooth
30,31,32	Glove	Mobile phone	Bluetooth

4 Challenges and Future Work

The first major issue associated with the application of the IoT in deafness and hearing loss management stems from security. As an unconventional network, it is possible for the IoT to be breached, leading to unauthorized access to information – cyber-attacks are becoming an increasing problem in the contemporary world, and healthcare has not been spared [23]. Different components of the IoT present various levels of risk for security vulnerabilities – for instance, wearable devices (which are relatively simple technologies without electronic encryptions) can be easily hijacked by unauthorized parties [23]. Alternatively, servers containing sensitive information may be hacked to provide unauthorized access to unscrupulous parties [24]. Therefore, this presents a challenge for the IoT-reliant healthcare profession, and the management of deafness and hearing loss is no different.

Legal issues also need to be considered in the use of the IoT in the management of deafness and healthcare. The US has laws such as HITECH and HIPAA that govern the access and use of patient health records see Fig. 4 for privacy rule and security requirements – when unauthorized access to this information occurs, the healthcare organization can be held legally liable and face litigation [25]. The protection of all manner of healthcare IoT is therefore a requirement for all healthcare organizations, especially considering that they generate both soft and hard copies of patient medical records [24]. Security challenges that result in unauthorized access to private (and sensitive) patient information and records can lead to violations of the aforementioned data privacy laws, fines and a loss of licensure. Alternatively, the patient can file a lawsuit against the healthcare organization, leading to compensatory payments [24]. Therefore, healthcare organizations that rely on the IoT to manage deafness and hearing loss have to contend with the legal framework surrounding its usage.

The last major issue relating to the use of the IoT in the management of deafness and hearing loss is poor connectivity. As indicated in the definition of the IoT, the devices involved in the network function in a wireless capacity – this can create issues when the different healthcare technologies are not compatible, to begin with [26]. As previously mentioned, a method commonly used by manufacturers is to ensure that the accessories and different spare parts they construct for their products are exclusive, thus assuring them of peripheral sales as posited by Kessler [26].

The view that connectivity issues can affect the IoT during the management of different medical conditions is also shared by [14]. This view is also shared by Yin et al., who cite completely incompatible healthcare technologies as compromising the

effectiveness of IoT networks [16]. Therefore, different components may be completely incompatible as per the manufacturers’ intentions, hence limiting the effectiveness of the IoT.

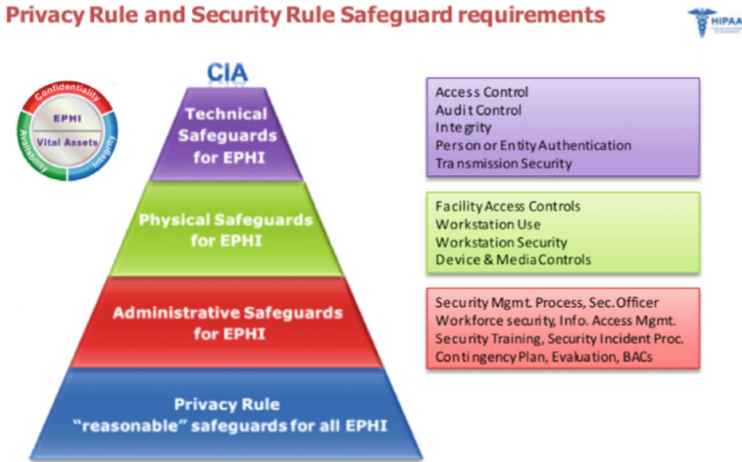


Fig. 4. Privacy Rule and Security Requirements [25]

Every connected device and application has potential security issues. When it comes to the security challenges facing IoT networks in the management of deafness and hearing loss, approaches involving high-end encryptions can be applied. The most recent development that can be employed by healthcare organizations is the use of blockchain technology – IBM states that “In most blockchains or distributed ledger technologies (DLT), the data is structured into blocks and each block contains a transaction or bundle of transactions. Each new block connects to all the blocks before it in a cryptographic chain in such a way that it is impossible to tamper with” [27]. Granted, blockchain technology is not completely foolproof, as it has some security shortcomings. However, its basis on decentralization and cryptography provides a robust foundation that cannot be easily breached, making it perhaps the most secure approach for the IoT [27]. Healthcare organizations should therefore invest in blockchain technology to protect the structural integrity of the IoT.

For future work, we are working on building an automated sign language recognition system using deep learning algorithms to recognize hand gestures. The system will assist in communication between ordinary individuals and hard-of-hearing people.

5 Conclusion

The development of IoT technology continues to meaningfully contribute to the health-care sector, opening new possibilities for improving people’s quality of life. People with disabilities, particularly those with hearing impairments, have fewer opportunities for social interactions, education, and access to modern technologies. These aspects are

crucial factors in developing their learning capacity and cognitive skills. Deafness and hearing loss are among the most understated public health concerns across the world. There are millions of people across the world who suffer from some form of hearing loss. Despite the obviously debilitating nature of these conditions, as demonstrated by many research papers using Google Scholar, a number of researchers have worked on improving and expanding the use of IoT technology in healthcare to serve deaf people. Not only do deafness and hearing loss lower the individual's quality of life, but also compromise their potential for academic and professional achievement. It is for this reason that this group requires assistive technologies that can deliver sound signals in a format they can comprehend and interpret. We are working on building a recognition system that can help in translating sign language to normal people and the reverse.

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