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A Review on Internet of Things (IoT)-Related Disabilities and Their Implications

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ABSTRACT

The transformative potential of the Internet of Things (IoT) extends to the lives of approximately one billion individuals worldwide living with disabilities, representing around 15% of the global population. This article highlights the importance of addressing challenges related to disability inclusivity and support, recognizing their significant impact on individuals and the global community. Despite inadequate support services, the IoT emerges as a beacon of hope, offering innovative solutions to empower people with disabilities. By integrating smart devices and technologies, the IoT can disrupt the cycle of dependence on families, thereby fostering economic activity and social inclusion. Introducing a proposed IoT framework elucidates its pivotal role in enhancing the quality of life for individuals with disabilities and facilitating their active engagement in societal and economic spheres. The article explores diverse application scenarios to underscore how the IoT can meet the unique needs of this demographic. Furthermore, it addresses critical challenges that must be acknowledged and overcome to implement IoT-based solutions in this context successfully. This study offers a comprehensive overview of IoT solutions tailored to mitigate the challenges encountered by individuals grappling with visual impairments.

KEYWORDS

IoT technology, disabled people, smart assistant, application, voice-recognition system

INTRODUCTION

The Internet of Things (IoT) holds significant promise for enhancing the lives of individuals with disabilities. By integrating smart devices and technologies, the IoT offers innovative solutions to address various challenges faced by people with disabilities and promote inclusivity (Alenizi and Al-Karawi, 2022a, 2023a). Through IoT-enabled assistive devices and applications, individuals with disabilities can gain increased independence, access to vital services, and improved overall quality of life (Vasco Lopes, 2020; Alenizi and Al-Karawi, 2022a). IoT devices with sensors, actuators, and connectivity enable real-time monitoring and support in healthcare, accessibility, and mobility. For instance, wearable devices can track vital signs and transmit data to healthcare professionals, providing timely medical assistance and personalized care (Khan et al., 2016; Alenizi and Al-Karawi, 2023b). Smart home technology can automate tasks, making living spaces more accessible and enabling individuals to control their environment through voice commands or other adaptive interfaces (Al-Karawi, 2021; Almusaed et al., 2023). Moreover, IoT-based navigation systems facilitate easy movement and accessibility in public spaces, ensuring that people with disabilities can navigate streets, buildings, and transportation with greater ease. While the IoT offers immense potential, it is crucial to address privacy and security concerns to protect the sensitive data collected by these devices (Farahsari et al., 2022; Al-Karawi 2023a). Furthermore, ensuring that IoT solutions are designed with universal accessibility principles will create an inclusive and empowering environment for people with disabilities (Shahrestani, 2017; Al-Karawi, 2023b). The IoT signifies a groundbreaking technological revolution that intertwines computing and communications. It paints a picture of a world where smart devices are seamlessly interconnected, as documented in the intensive therapy unit (ITU) internet reports, and possess digital identities (ID) (Lachtar et al., 2017; Al-Karawi and Ahmed, 2021). By amalgamating the internet and emerging technologies such as

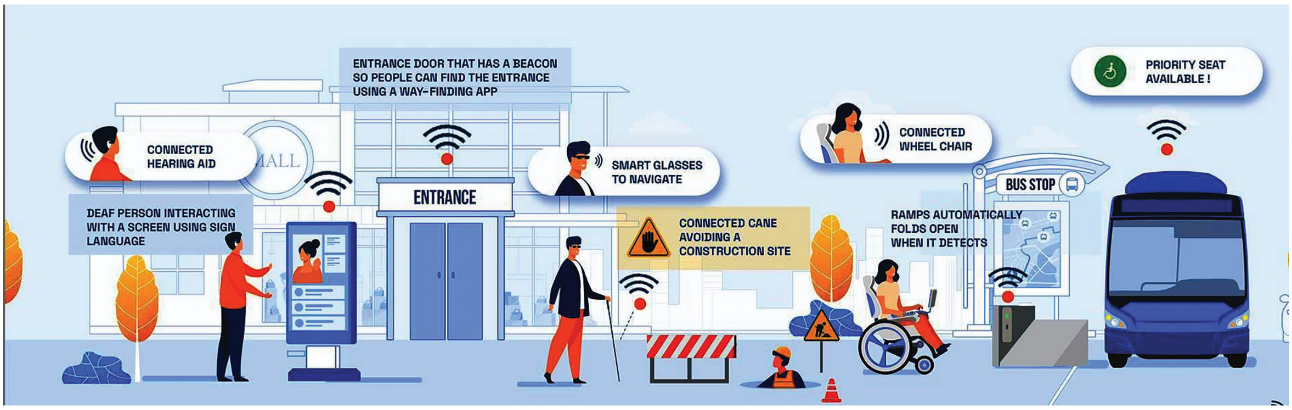

Figure 1: IoT-based assistive technologies for disabled people (Bansal and Garg, 2021). Abbreviation: IoT, Internet of Things.

radio-frequency identification (RFID) (Amaral et al., 2011; Al-Karawi and Mohammed, 2019), real-time localization, and embedded sensors, ordinary objects transform into smart entities capable of perceiving, interpreting, and responding to their environment. This technological advancement paves the way for novel communication between individuals, the objects they interact with, and these interconnected objects themselves (Tan and Wang, 2010; Al-Karawi and Mohammed, 2021). Figure 1 shows the IoT-baxsed assistive technologies for people with disability.

In June 2011, the World Health Organization (WHO) released the inaugural World Report on Disability, shedding light on the worldwide disability scenario. Drawing from population figures as of 2010 (6.9 billion) and disability prevalence estimations from 2004 (Murray et al., 2007; Krahn, 2011; World Health Organization, 2022), approximately one billion individuals, encompassing children, which equates to around 15% of the global populace, are believed to be grappling with varying forms of disabilities (Krahn, 2011; Mohammed et al., 2021). According to the WHO report, within this demographic, 110 million individuals encounter substantial challenges in their daily functioning. Simultaneously, 190 million fall into the category of "severe disability," akin to conditions like quadriplegia, profound depression, or complete blindness (Krahn, 2011; Frontera, 2012). Furthermore, a recent 2010 study conducted by the Organization for Economic Co-operation and Development sheds light on the significant labor market disparities experienced by people with disabilities. On average, the employment rate for people with disabilities was only 44%, compared to 75% for those without disabilities. Similarly, the inactivity rate, indicating those not participating in the labor force, stood at 49% for people with disabilities and only 20% for those without disabilities. Discrepancy data reveal that disabled individuals face an inactivity rate that is approximately 2.5 times higher than that of their nondisabled counterparts. Adding to these challenges, the absence of essential support services, such as accessible infrastructure, transportation, and efficient information systems, can result in disabled individuals relying heavily on their families for assistance. This paper explores the potential of the IoT to improve the quality of life and engagement of individuals with disabilities, including those with visual, auditory, and physical impairments. This highlights the importance of integrating assistive IoT technologies to enhance independence and social involvement (Vasco Lopes, 2020; Semary et al., 2024).

This paper offers an extensive overview of the potential benefits of the IoT for individuals facing disabilities. The review of IoT-related disabilities aims to achieve several objectives. Primarily, it systematically identifies and evaluates existing IoT solutions designed to address the needs and challenges of individuals with disabilities. Through this review, the paper assesses the effectiveness and usability of IoT technologies in improving accessibility, independence, and overall quality of life for this demographic. Additionally, the review explores emerging trends, innovations, and best practices in developing and implementing IoT-related solutions for disabilities. It covers a broad spectrum of disabilities, including visual, hearing, mobility, and cognitive impairments, while examining diverse IoT technologies and application domains. By shedding light on accessible and innovative IoT solutions, the review contributes to informing policy and practice, fostering innovation, and empowering individuals with disabilities to fully participate in society. The paper is organized into the following sections: The IoT for People with Disabilities section discusses on why we should focus on the IoT for people with disabilities, followed by the IoT Framework section. The next is the Application Scenarios section, followed by the Advantages of IoT for Individuals with Disabilities section. The challenges in implementation is discussed in the Challenge in Research section, and the article ends with the Conclusion section.

IOT FOR PEOPLE WITH DISABILITIES

The IoT is a vast network of connected devices that collect data from the physical world, offering various conveniences and lifestyle improvements (Alenizi and Al-Karawi, 2022b). While many papers have discussed the general promise and privacy concerns of the IoT, there is a scarcity of research addressing the specific privacy implications of IoT use by people with disabilities. Since approximately 15% of the world's population lives with some form of disability, their unique needs and preferences demand more exploration (Das et al., 2017; Vasco Lopes, 2020). The potential benefits of developing IoT devices and services tailored for people

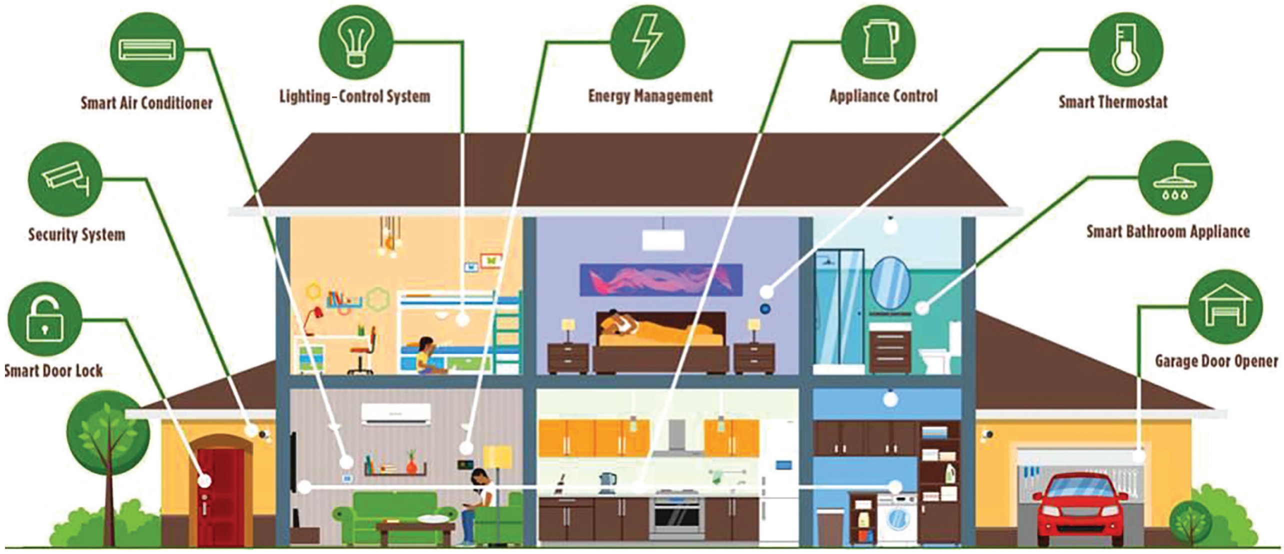

Figure 2: Control devices connected via smartphone (Mnati et al., 2017).

with disabilities hold tremendous significance, as they can significantly enhance their quality of life and open up new opportunities for accessibility and inclusivity (Rose et al., 2015; Abdelwahab et al., 2024). The IoT can potentially transform the lives of people with disabilities, as it offers opportunities to enhance safety, mobility, and independence, leading to improved privacy. IoT technology has given rise to many innovative devices and services tailored to the needs of individuals with disabilities, aiming to empower them and reduce their reliance on external assistance. A few notable examples include the following (Das et al., 2017):

- Internet-connected prosthetics: IoT-enabled prosthetic limbs with sensors can provide real-time feedback and adapt to the user's movements, significantly improving mobility and functionality.
- Smart shoes: Shoes equipped with IoT technology, such as vibrating sensors, can guide individuals with visual impairments by providing navigational cues and helping them navigate safely in their environment.
- Home automation: IoT-based smart home systems can be customized to cater to the specific needs of people with disabilities, allowing them to control various aspects of their living space, such as lighting, temperature, and appliances, through voice commands or other adaptive interfaces.
- Health-monitoring devices: IoT-powered wearable devices can monitor vital signs and health metrics, providing individuals with disabilities and their caregivers with valuable data for timely medical interventions and personalized care.
- Assistive communication devices: IoT devices with speech recognition capabilities can facilitate communication for individuals with speech impairments, enabling them to interact more effectively with others and access various services. Figure 2 shows the control devices connected *via* smartphone applications.

These examples illustrate how the IoT can revolutionize the lives of people with disabilities, fostering independence, enhancing safety, and promoting inclusion in society. The potential for further transformative applications in this field is vast as IoT technology advances. Besides the numerous benefits of accessible IoT devices and services, they also present the opportunity to gather more data about people with disabilities, bringing advantages and challenges (Tsatsou, 2020). One significant benefit is bridging the "data divide," addressing the scarcity of high-quality data about specific individuals or communities. By mitigating this gap, it becomes possible to enhance policymaking, allocate resources more effectively, and develop improved products and services tailored to the needs of people with disabilities. Ultimately, this can reduce social and economic inequalities (Al-Karawi et al., 2015; Hollier and Abou-Zahra, 2018).

Moreover, universal and accessible designs are vital in enhancing accessibility. Universal design involves creating products, buildings, public spaces, and programs to be usable by the widest range of people possible. On the other hand, accessible design focuses on explicitly considering the needs of people with disabilities during the design process. This approach ensures that advancements in the IoT, such as closed-captioning technologies and virtual assistants, benefit not only people with disabilities but also everyone in society. Interestingly, many technologies widely enjoyed by the general public, such as auto-complete and voice-recognition features, were initially designed to assist people with disabilities in using computers (Rghioui and Oumnad, 2018; Al-Karawi and Mohammed, 2023). This principle, known as the "curb-cut effect," illustrates how society benefits from innovations to aid vulnerable groups. For example, curb cuts initially meant for wheelchair users now help various individuals, including parents, with strollers and shoppers carrying groceries, making walking the streets more accessible. In conclusion, accessible IoT devices not only enhance the lives of people with disabilities but also foster inclusivity and improve the overall quality of life, demonstrating the potential positive impact of designing with diverse needs in mind (Mouha, 2021).

IOT FRAMEWORK

Figure 3 presents the proposed IoT architecture from a technical perspective, organized into three layers. Let's briefly summarize the functionalities of each layer. A typical IoT architecture consists of three main layers:

Perception layer

The perception layer provides context-aware information for disabled individuals, providing insights about their surrounding environment. Within this layer, specific components are designed to cater to the needs of individuals with different disabilities, including visual impairment, hearing impairment, or physical impairment (Schwiebert et al., 2001).

Visually impaired

The components designed to aid the visually impaired consist of body micro- and nanosensors. These sensors are miniaturized devices integrated into wearable accessories or clothing. They capture and process real-time data about the wearer's surroundings, providing context-aware information through tactile feedback or auditory cues. RFID-based assistive devices are devices that utilize RFID technology to assist visually impaired individuals in object identification and navigation. RFID tags embedded in objects communicate with RFID readers carried by the individual, conveying essential information about the objects' location and characteristics. Let's introduce these components in more detail in the following paragraphs.

The first category, body micro- and nanosensors, refers to tiny sensing devices integrated into smart gloves, glasses,

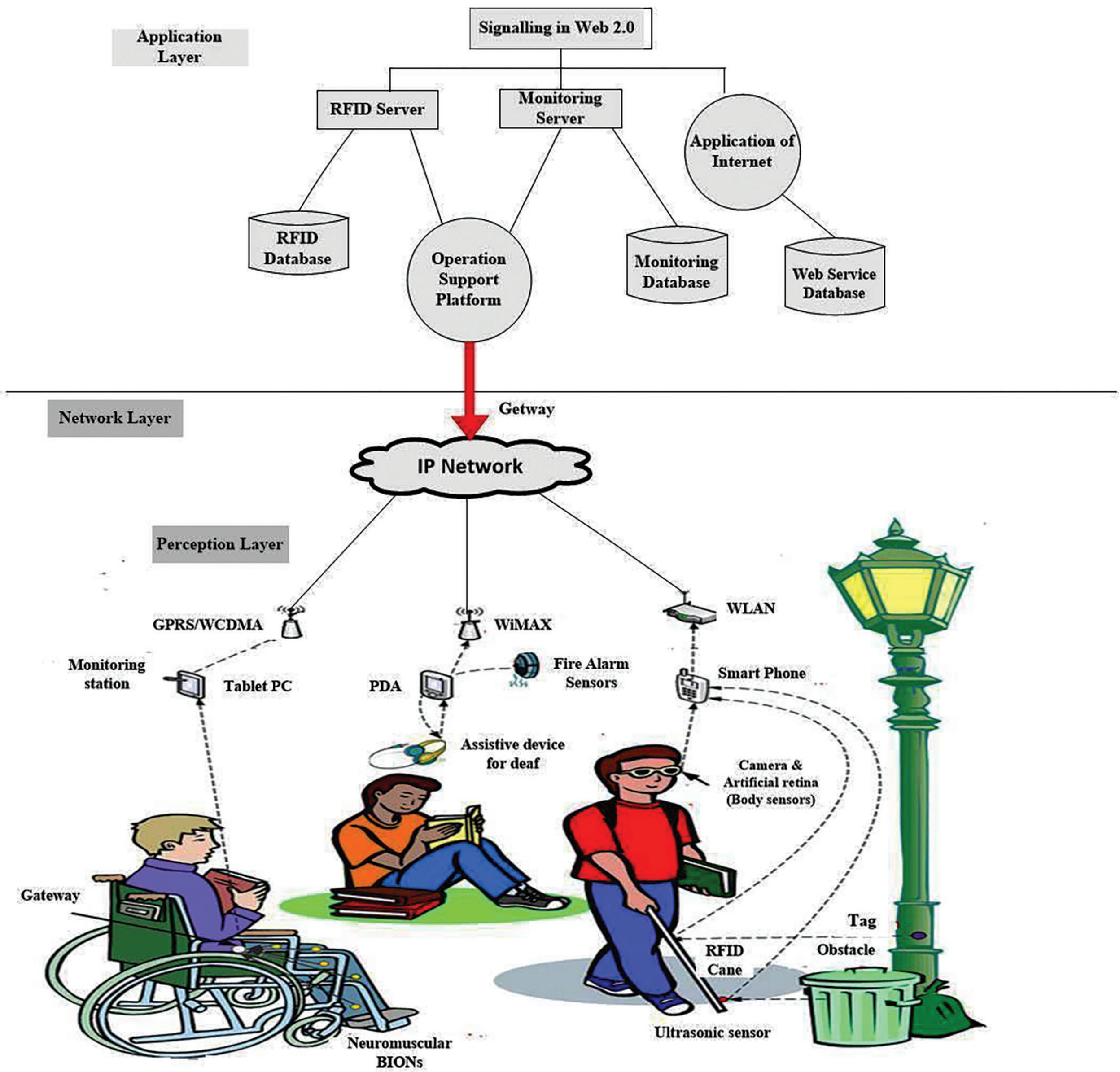

Figure 3: The IoT architecture proposed is analyzed from a technical standpoint. Abbreviations: BION, (wilfred ruprecht Bion) was an influential English psychoanalyst; IoT, Internet of Things; RFID, radio-frequency identification; PC, personal computer; WCDMA, wideband code division multiple access; WiMAX, worldwide interoperability for microwave access.

or canes. These sensors continuously monitor the environment, detecting obstacles, changes in terrain, or the presence of objects. The data collected by these sensors are then processed and relayed to the user through tactile vibrations or auditory cues, providing valuable context-aware information about their surroundings. The second category, RFID-based assistive devices, utilizes RFID technology to facilitate object identification and navigation for the visually impaired. RFID tags are attached to various objects or landmarks, such as doorways, bus stops, or specific items in a store. When a visually impaired individual with an RFID reader approaches these tagged objects, the reader wirelessly communicates with the tags, relaying relevant information about the object's ID and location to the user. This assists the individual in navigating their environment more effectively and independently. Together, these components offer significant support to visually impaired individuals, enhancing their mobility, safety, and overall independence by providing valuable context-aware information.

Body micro- and nanosensors

Schwiebert et al. (2001) devised a retinal prosthesis to regain vision for individuals afflicted with retinitis pigmentosa and age-related macular degeneration, two progressive conditions leading to blindness. Although these conditions result in the gradual deterioration of photoreceptor cells in the outer retina, including rods and cones, they do not impact the inner retinal ganglion nerve cells that constitute the optic nerve (Bhatnagar et al., 2019). The retinal prosthesis uses eyeglasses to transmit image data to an implant connected to the retina, which activates microsensors and converts electrical impulses into neurological signals, partially restoring vision in degenerative diseases (Ye et al., 2010; Chaudhari et al., 2016). Scientists are developing a nanoscale artificial retina, the bio-retina project, which uses specialized activation eyeglasses to transform natural light into electrical signals for image relay (Sarkar et al., 2023) (Figure 4).

RFID-based assistive devices

RFID-based navigation systems aid blind individuals in unfamiliar areas by strategically placing RFID tags at the center of sidewalks, providing orientation cues, and preventing accidental falls (Hafsi and Thomas, 2005; Saaid et al., 2009). By detecting and interacting with these RFID tags using a handheld or wearable RFID reader, blind people can receive audible or tactile feedback, helping them stay on course and avoid potential hazards. This RFID-based navigation system is invaluable in empowering blind individuals to explore new environments with increased confidence and independence, enhancing their overall mobility and safety (Kher Chaitrali et al., 2015). As shown in Figure 3, the RFID cane is designed with a tag reader featuring an antenna capable of emitting radio waves. In return, the RFID tags positioned in the surroundings respond by sending their stored data, effectively pinpointing the blind person's location. This RFID cane, serving as a tag reader, transmits the data acquired from the RFID tag using Bluetooth or ZigBee communication protocols. The transmitted data encompass the unique ID string associated with the tag (D'Atri et al., 2007; Li et al., 2018). The information captured by the RFID cane is transmitted from the monitoring station *via* the network layer to the RFID server situated in the application layer. Individuals with visual impairments can save the destination's name at the monitoring station as a voice message. After registration, the monitoring station retrieves and conveys navigational directions to the destination as voice messages, facilitating efficient navigation for the visually impaired person (Shiizu et al., 2007; Fukasawa and Magatani, 2012). The RFID-based navigation system in the cane enhances the autonomy and safety of visually impaired individuals by providing real-time guidance

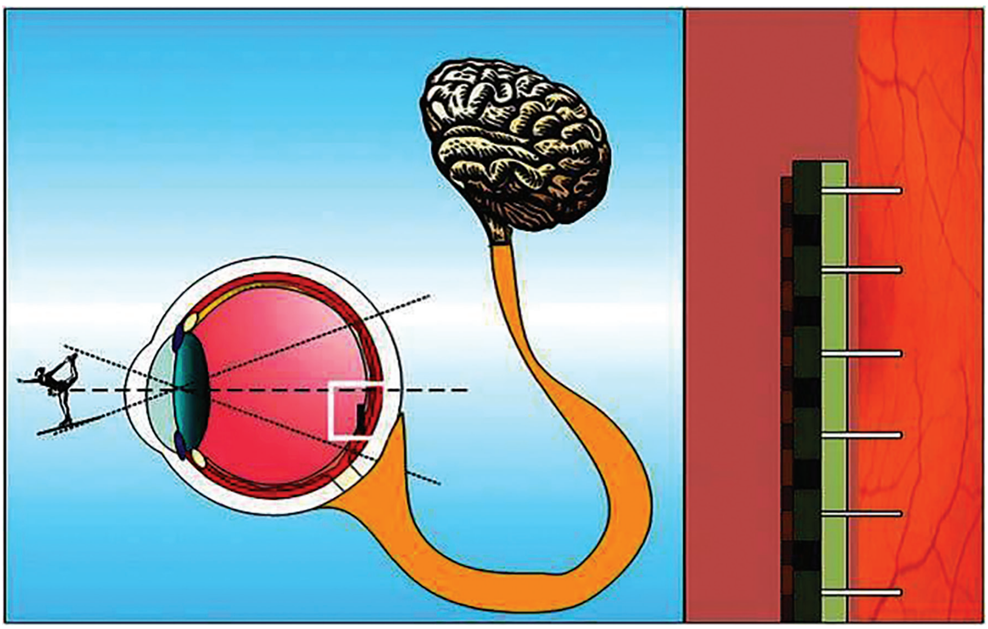

Figure 4: Positioning of the retinal implant (left); bionic chip and its interface with the retina (right) (Ayton et al., 2020).

and obstacle detection. This additional feature enhances the safety and mobility of the blind person further. The ultrasonic sensor can detect objects and obstacles in the blind person's path by emitting high-frequency sound waves and measuring the time it takes for the waves to bounce back after hitting an object. When the ultrasonic sensor detects an obstacle within a specific range, it sends a signal to the monitoring station on the RFID cane (Yu and Marinov, 2020). The RFID cane, a combination of RFID-based navigation and an obstacle detection system with an ultrasonic sensor, offers real-time information to blind individuals, enhancing their confidence and safety during navigation, providing immediate feedback in the form of audible alerts or vibrations (Ruder et al., 2003; Discant et al., 2007).

This layer is at the bottom and represents the physical world where data are sensed and collected. It includes sensors, actuators, monitoring stations (e.g. smartphones, tablets, etc.), RFID tags, and readers/writers (Schwiebert et al., 2001). The perception layer in an IoT system provides contextually relevant information for people with disabilities, using tactile sensors and advanced image recognition systems (Ye et al., 2010).

Vibrating sensors enable deaf individuals to perceive sounds through touch, while motion sensors detect movement and gestures. Physically impaired individuals use robotic devices, actuators, and artificial intelligence (AI) algorithms for mobility support and object manipulation.

Network layer

The network layer in the IoT facilitates seamless data exchange between devices and procedures, encompassing wired and wireless networks, private networks, the internet, and network administration systems, serving as the backbone for connecting IoT devices to various networks (Bello et al., 2017). The network layer manages protocols like Wi-Fi, Bluetooth, cellular, and low-power wide area network (LPWANs) based on range, power efficiency, and data requirements. It ensures the unique identification of IoT devices, manages routing, forwarding, and mesh networking, and prioritizes security through encryption, authentication, and authorization (Gokhale et al., 2018).

Application layer

This layer represents user-centric intelligent solutions built on the IoT architecture. It comprises various applications and services that leverage the data collected from the perception layer and processed by the network layer. These intelligent applications cater to specific user needs and provide valuable insights and services. The application layer in the IoT is where IoT systems' true value and functionality come to fruition (Karagiannis et al., 2015). The application layer in the IoT architecture processes and analyzes data from devices, enabling specific applications and services for various industries. It uses protocols and application programming interface (APIs) to create custom software, dashboards, and interfaces, incorporating machine learning and AI algorithms for real-world benefits and customization (Yassein and Shatnawi, 2016).

APPLICATION SCENARIOS

Here, we present several application scenarios of the IoT specifically created to aid individuals with disabilities. These scenarios illustrate the smooth integration of diverse elements within the IoT framework. Table 1 shows the main applications of the IoT.

Table 1: The applications of the IoT.

IoT applications for people with disability	Description
Smart wearable devices	Wearable devices equipped with sensors and assistive technologies for individuals with disabilities, such as smartwatches with health-monitoring features or navigation aids for the visually impaired.
Assistive smart home automation systems	Smart home automation systems are designed to enhance accessibility and independence for individuals with disabilities, including voice-controlled devices, automated lighting, temperature control, and door locks.
IoT-enabled mobility aids	Mobility aids integrated with IoT technology to assist individuals with mobility impairments, such as smart wheelchairs with navigation and obstacle detection capabilities or robotic exoskeletons for mobility assistance.
Communication and speech-assistive technologies	IoT-based communication aids and speech-assistive technologies for individuals with speech and hearing impairments, including speech-to-text and text-to-speech conversion tools, communication boards, and smart communication devices.
Remote health-monitoring systems	IoT-enabled health-monitoring systems for individuals with chronic conditions or disabilities allow the remote monitoring of vital signs, medication adherence, and health status through wearable sensors and smart medical devices.
Smart assistive devices for daily living activities	IoT-based assistive devices support daily living activities for individuals with disabilities, including smart kitchen appliances, adaptive utensils, and home safety devices with remote monitoring and alerts.
Navigation and way-finding tools	IoT-based navigation and way-finding tools for individuals with visual impairments, including smart canes, wearable navigation aids, and indoor positioning systems that provide real-time navigation and location information (Figure 5).

Abbreviation: IoT, Internet of Things.

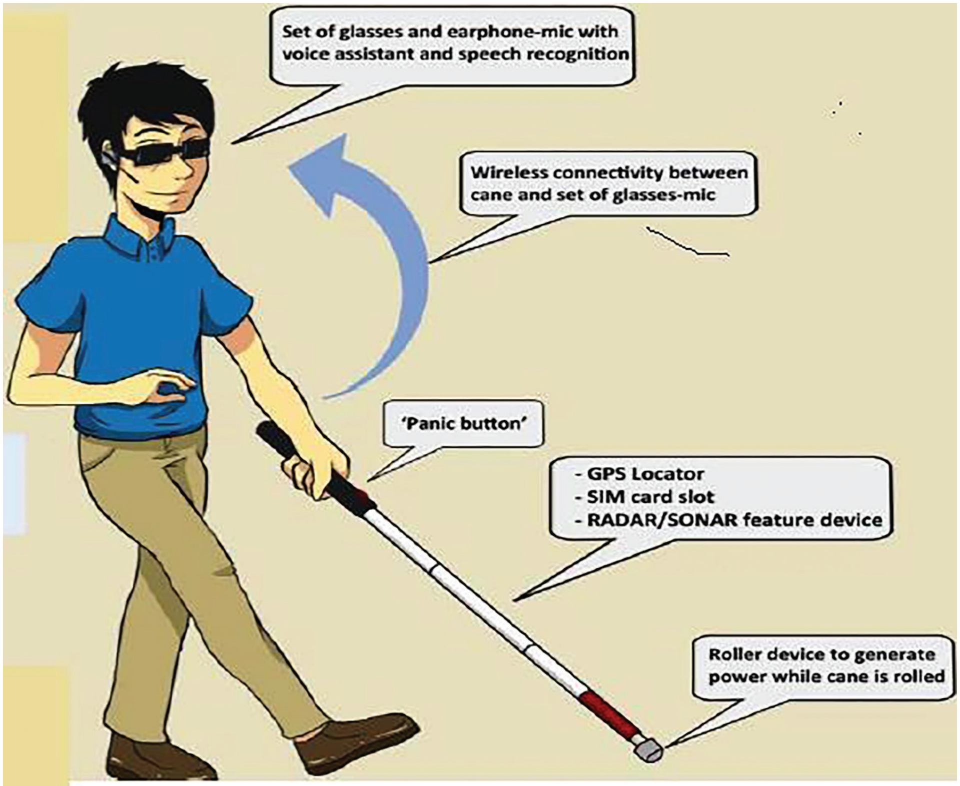

Figure 5: The smart cane (Nandini et al., 2019). Abbreviations: GPS, global positioning system; RADAR, radio detection and ranging; SIM, subscriber identification module; SONAR, sonic navigation and ranging.

A shop situation

The integration of IoT in shopping enhances convenience, optimizes store operations, and provides a personalized shopping experience for all customers, including those with disabilities. A study by López-de-Ipiña et al. (2011) introduced a blind navigation system using RFID tags. A supermarket has a smartphone-based monitoring system for visually impaired individuals to assist them during shopping trips. The system uses RFID tags and a Bluetooth-connected monitoring station with a smart cane, allowing users to specify the supermarket section they want to visit. The system uses wireless local-area network (WLAN) to determine optimal routes, providing real-time routing instructions *via* an Android application. RFID tags on supermarket products offer crucial information, including product name, description, and price. The RFID cane transmits tag ID to a monitoring station, which retrieves product details and relays them to the user (Figure 6).

Furthermore, RFID tags can store additional product attributes, including nutritional content, calorie information, and user-specific details such as dietary allergies and intolerances. Additionally, social media platforms can be utilized to collect insights, such as product reviews from friends or price comparisons with similar items. In a study by Krishna and colleagues, experiments were conducted to evaluate the detection range of RFID readers for different types of tags and materials in which these tags were integrated (Krishna et al., 2010). The results showed that the RFID readers' performance was unaffected by the materials of the products. Numerous real-world studies have been conducted in this application context (Kulyukin and Kutiyanawala, 2010; Hakobyan et al., 2013; Stangl et al., 2018).

In the research conducted by Lanigan et al., they present "Trinetra," a system explicitly created to aid visually impaired individuals in locating and identifying products during grocery shopping (Lanigan et al., 2006; Narasimhan, 2006). When individuals with visual impairments scan a grocery item using a portable barcode or RFID reader, the scanned data are transmitted *via* Bluetooth to their smartphone. The smartphone initiates the process by checking locally stored data for a potential product match. The phone communicates *via* general packet radio services (GPRS) with a remote server if no match is found in the cache. It also has the option to query a public Universal Product Code or RFID database for additional information. The remote server or database takes the barcode or tag data and translates them into a user-friendly product name and relevant details, which are then transmitted back to the smartphone. Equipped with an integrated text-to-speech software, the smartphone converts the text displayed on the screen into spoken words, providing valuable assistance to individuals with visual impairments in identifying the product. RFID tags offer several advantages over barcodes, including their reprogramming capability, capacity to store more comprehensive product data, and the ability to be read without requiring a direct line of sight (Narasimhan, 2006; Hakobyan et al., 2013). Trinetra was subjected to a successful trial at the Carnegie Mellon University campus store, confirming its practicality and efficiency in assisting shoppers with visual impairments.

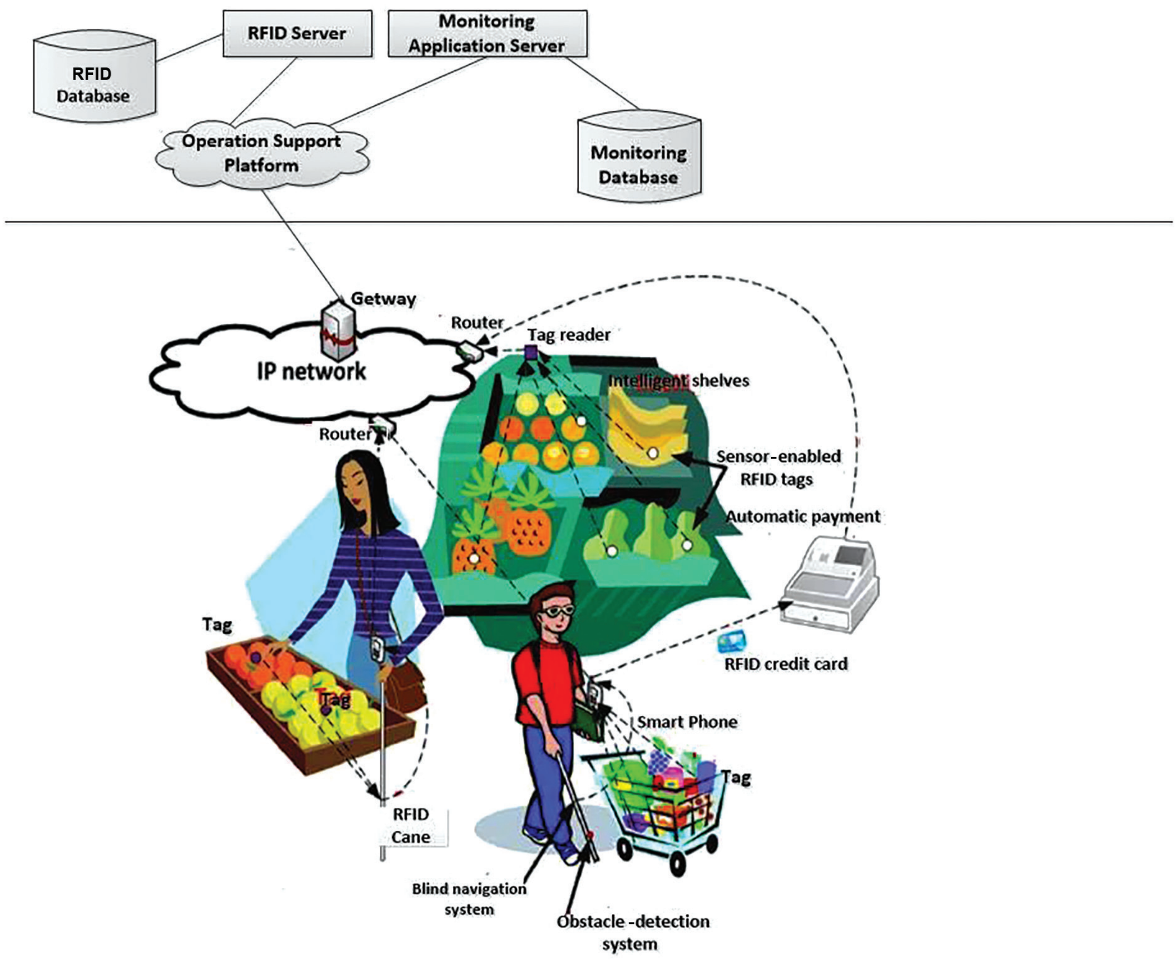

Figure 6: The shopping situation (Perera et al., 2021). Abbreviation: RFID, radio-frequency identification.

Local environment

Smart home technology is a collection of interconnected devices, appliances, and systems that enhance convenience, efficiency, security, and quality of life through automation and remote control, allowing homeowners to manage various aspects of their home environment (Suresh and Sruthi, 2015; Wilson et al., 2017). The technology often utilizes sensors, Wi-Fi connectivity, and AI to enable seamless communication and interaction between different devices, creating a more integrated and responsive living space (Martin et al., 2008). Smart homes facilitate the automatic management and regulation of the household setting through various devices, including automated kitchen appliances, controllers for lighting and doors, indoor temperature regulators, water temperature adjusters, and home security systems (Stefanov et al., 2004). Home automation systems use sensors and actuators to monitor environmental conditions, process data, and communicate with devices *via* wireless networks. These data are relayed to a central server for user services. Actuators respond to emergencies like burglary or fire. RFID technology is integrated into the smart home environment for efficient identification and tracking, bridging automation, security, and convenience (Alsinglawi et al., 2017). RFID technology enhances smart home intelligence, allowing personalized experiences, enhanced security, and data insights. It optimizes resource usage, refines daily routines, and improves user interaction in living spaces (Hussain et al., 2009). Figure 7 shows the smart watch for blind people. In their study, Darianian and Michael (2008) introduced a master-slave RFID framework. The system architecture integrates slave readers within various home appliances, enabling communication with mobile readers, monitoring stations, and a central master reader. This master reader is connected to a smart home server. Multiple master readers

Figure 7: Smartwatches for blind people (Marques, 2023).

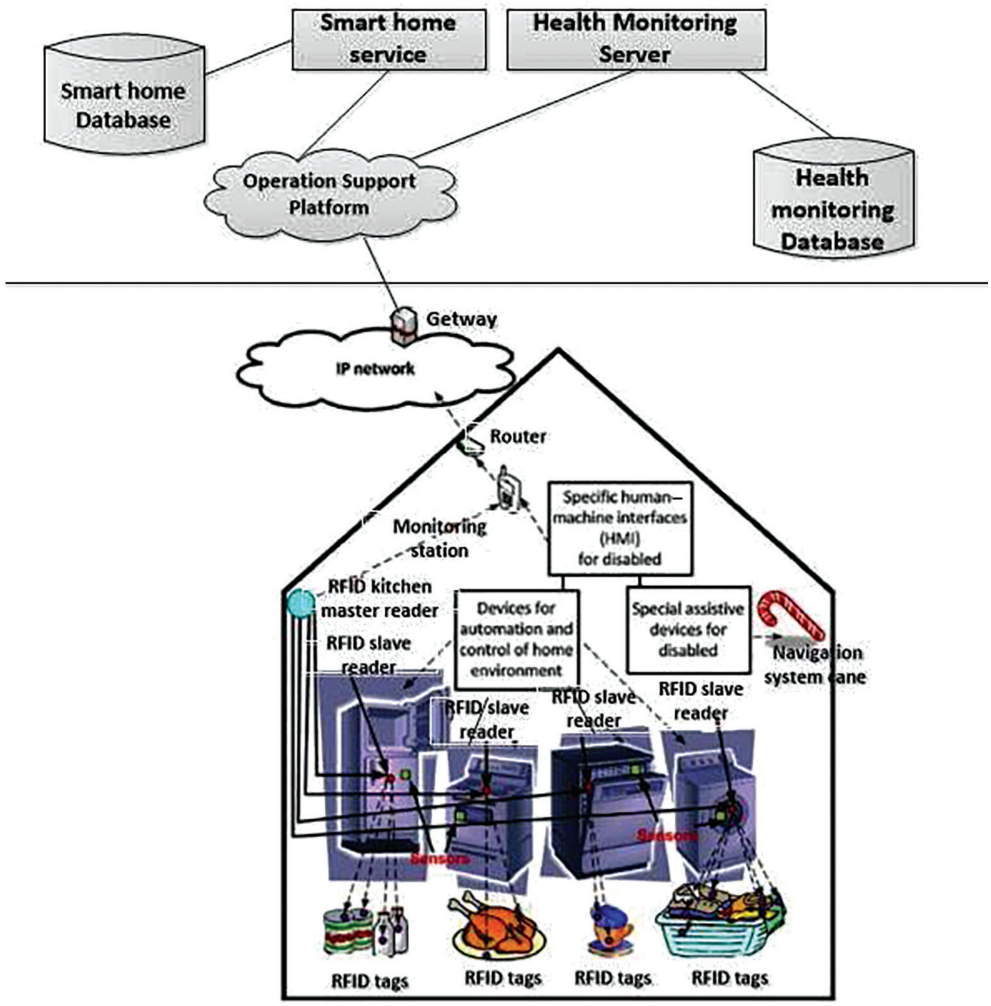

Figure 8: The smart home situation (Domb, 2019). Abbreviation: RFID, radio-frequency identification.

can be shared among mobile readers. This framework serves as the foundation for managing home laundry, as depicted in Figure 8. Each clothing item has RFID tags that store vital information such as color, material, and suitable washing programs. An automated alert is triggered when an RFID reader detects a threshold quantity of soiled clothes, suggesting an energy-efficient washing program.

Additionally, the reader verifies the compatibility of clothing items as they are loaded into the washing machine. In conjunction with a database, the smart home server facilitates monitoring the next batch of soiled laundry designated for the upcoming washing cycle. Moreover, other applications leverage the synergy of internet services and RFID identification within the context of smart homes. Slave readers embedded in household appliances like refrigerators and shelves establish connections with a master reader in the kitchen. This interaction leads to recommending customized cooking recipes based on the resident's preferences and health considerations, which may encompass factors like food allergies or cholesterol levels. This process involves the use of web services for recipe search and retrieval. Furthermore, a health-monitoring server and database play a vital role in monitoring and recording the resident's health status. Additionally, the smart home server and database maintain records of the resident's inventory of essential food items and assess their availability. This information is then compared to generate an automated shopping list (Domingo, 2012). Moreover, automation logic aimed at optimizing daily power consumption is presented in the work by Buckel et al. considering the external electricity price obtained from a web service; this approach reduces energy usage within the household. For instance, approaches like disconnecting the home from the power grid and utilizing stored battery energy or activating energy-conservation modes for appliances like refrigerators are implemented until certain temperature thresholds are met. A prospective home automation scenario is outlined for illustrative purposes (Buckl et al., 2009). Modern residences equipped with sensor-embedded systems, commonly called smart homes, can play a crucial role in assisting individuals with impairments and addressing their social isolation (Chan et al., 2008). Smart homes are tailored to accommodate individuals with disabilities using two distinct approaches: (i) Customized interfaces are developed to streamline the operation of home automation and control devices; and (ii) specialized assistive devices are crafted to enhance their living conditions within the home.

The specific interfaces required to aid disabled individuals in managing smart homes are outlined in the following text, as elaborated in Stefanov et al. (2004).

- Individuals with visual impairments necessitate a specialized human–machine interface (HMI), a user interface designed to facilitate communication and interaction between humans and specific machines or systems, often tailored to them.

Specialized HMIs are designed to cater to specific domain, industry, or user group needs, tasks, and limitations, unlike generic HMIs, which serve a broader range of applications (Peschel and Murphy, 2012; Boy, 2017). An alternative approach to improve their vision is using retinal prostheses (Schwiebert et al., 2001). Additionally, employing voice control for devices installed in their homes is a suitable method. Revamping human–machine interaction (HMI): People affected by severe paralysis can find value in specialized head-tracking devices that provide up to three proportional signals, allowing forward–backward head tilting, left–right head rotation, and lateral head tilting. Several techniques contribute to this domain, including facial detection, eye movement control, brain interfaces, gesture recognition, and facial expression analysis. In a study conducted by Ju et al. (2009) and Ruzaij and Poonguzhali (2012), they introduce an innovative and intelligent wheelchair that calculates its path based on the inclination of the user's face and stops movement based on the shape of the user's mouth (Ju et al., 2009; Ruzaij and Poonguzhali, 2012).

Requirements of hearing-impaired people

Specialized human–machine interface (HMI)

Touchscreens are utilized for accessing graphical data and reading text. Assistive devices tailored for the deaf community offer valuable support. Summarized below are several instances of specialized assistive devices designed to enhance the living conditions at home for disabled individuals:

Indoor navigation tools

A navigation system based on voice-synthesized instructions and an obstacle detection system serve as valuable assistance tools (Saaid et al., 2009; Shaha et al., 2018). Examples include powered wheelchairs and specialized lifting mechanisms designed to transfer users between beds and wheelchairs (Ahmad and Tokhi, 2011). They have unveiled an innovative two-wheeled wheelchair that can elevate its front wheels (casters), allowing users with mobility limitations to attain an upright position. This advancement empowers individuals to reach elevated heights and handle items on shelves effectively. Within robotic movement assistance systems, rehabilitation robots are engineered to aid individuals in tasks like sitting and object manipulation. Satoh and colleagues introduced a method for providing bathing care assistance through the hybrid assistive limb (HAL) robot suit. These assistive devices may also integrate specialized human–machine interfaces (HMIs) as needed, ensuring effective operation for individuals with disabilities (Satoh et al., 2009).

In education

Integrating the IoT into education revolutionizes traditional learning environments. In this dynamic scenario, classrooms are becoming intelligent and interactive, equipped with various connected devices. These devices, including interactive whiteboards, tablets, and sensors, empower educators to deliver more engaging and personalized lessons (Marquez et al., 2016; Kim and Smith, 2017). IoT in education goes beyond the classroom, extending to administrative functions such as campus security and energy management. IoT-powered security systems enhance safety, while energy-efficient solutions optimize resource usage (Pei et al., 2013). IoT facilitates remote learning, asset management, and attendance tracking in education, promoting innovation and improving outcomes. However, careful consideration of data privacy and security is needed to protect students and staff (Axelsson et al., 2014; Ramlowat and Pattanayak, 2019). Figure 9 illustrates a school scenario highlighting the benefits of intelligent interactive play and educational environments for toddlers aged 1.5-4 years, especially those with multiple disabilities (Martin et al., 2008). These systems aim to enhance their language and communication abilities. These play and learning environments utilize RFID technology to identify different objects, including children's toys like sheep (Hengeveld et al., 2009). Moreover, RFID-tagged toys assist deaf children aged 3-4 years in learning sign language (Parton et al., 2010). The software enables children to scan an item's tag, capture its unique identification number, and send it to a computer's software, triggering an animation featuring videos and avatars (Hengeveld et al., 2009), underscoring the significant advantages of creating intelligent interactive play and learning environments tailored for toddlers aged 1.5-4 years, especially those with multiple disabilities. These innovative systems are specifically crafted to boost their language and communication capabilities.

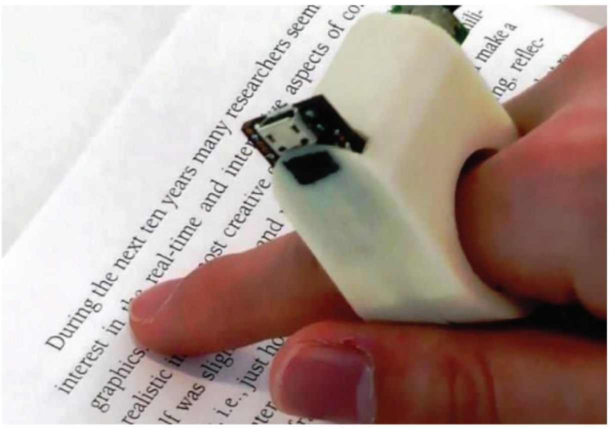

Figure 9: Finger reader (Siregar and Siagian, 2022).

Furthermore, RFID-tagged toys are instrumental in aiding deaf children aged 3-4 years in learning sign language, as elaborated in Hengeveld et al. (2009), emphasizing the substantial benefits of developing intelligent interactive play and learning environments for toddlers aged 1.5-4 years, particularly those with multiple disabilities. These innovative systems are designed to enhance their language and communication skills. Additionally, RFID-tagged toys assist deaf children aged 3-4 years in learning sign language, as detailed by Goldin-Meadow and Feldman (1975); Parton et al. (2010); Lieberman et al. (2014). The software enables a child to utilize an RFID reader to scan a tag attached to an item, capturing its distinct identification number and transmitting it to the computer's software through a universal serial bus (USB) connection. An animation is initiated, featuring videos of a person alongside an avatar. Additionally, these systems support the learning process by signing the item's name [in American Sign Language (ASL)] and displaying various images of the object to acquaint the child with different variations of the item, such as multiple types of ships. Figure 10 illustrates the finger reader.

The Louisiana School for the Deaf implemented a bilingual approach to language acquisition, incorporating technology into their 4-week early childhood curriculum, resulting in positive outcomes (Parton et al., 2009). Furthermore, the research conducted by Parton et al. (2010) concluded that inexpensive RFID tags and readers proved more appropriate than low-cost barcode readers/tags within an educational environment (examined with elementary school students in grades K-6). The RFID technology achieved a success rate of 99% in launching animations, compared to only 26% with barcode technology. RFID technology demonstrated rapid success, with successful scans occurring in as little as 1-15 seconds for 96% of launched animations. Currently, information about the tagged objects is stored on a computer. However, for enhanced efficiency, it is proposed that an RFID server and database be employed to manage the application. The multimedia videos could also be stored and accessed *via* an application server. There is also the suggestion that the tag reader could simultaneously scan multiple objects to establish connections between different items and their corresponding nouns. In such scenarios, a new multimedia video would be initiated, incorporating sign language and offering examples of the objects collectively. Single microchip tags could also be affixed to the same thing, forming an RFID grid. As an illustration, the reader might scan a doll with tags on various body parts to trigger informative videos. This approach allows children to learn to distinguish different body parts. The

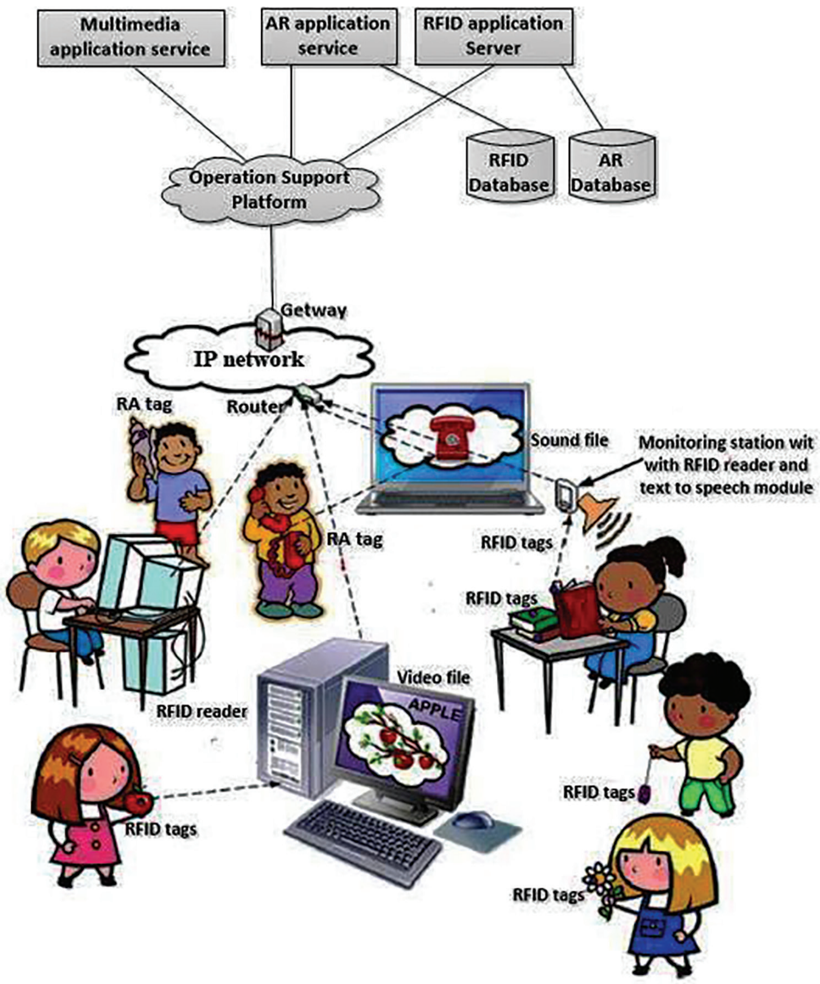

Figure 10: Education scenario (Giannakas et al., 2023). Abbreviations: AR, augmented reality; IP, internet protocol; RFID, radio-frequency identification.

technology allows children to engage in experiential learning at zoos or farms using tag readers and monitoring stations.

The RFID server retrieves information about the scanned object, triggering the playback of a multimedia video. Augmented reality (AR) merges real-world and computer-generated environments. A computer program recognizes AR objects and their tag IDs, allowing it to display them on the screen, play real-time audio files, and incorporate AR tags into picture cards, creating a virtual sound with real imagery (Chien-Yu et al., 2010). This method aids children with sensory or cognitive challenges in understanding typical everyday sounds. Furthermore, it facilitates the learning of different materials by visually impaired children by combining tactile sensations with audio descriptions, allowing them to explore various materials through their sense of touch (Chien-Yu et al., 2010; Ivanov, 2010). Research on young children with physical disabilities demonstrates AR as an efficient assistive technology, engaging them in interactive experiences with plant elements (Richard et al., 2007). The interactive setup involves children manipulating an object using an AR system, using visual, auditory, and olfactory cues to guide them in placing it correctly, using visual, auditory, and olfactory cues. Moreover, RFID technology is crucial for children with visual impairments in helping them locate specific books. These books can then be "read" to them using a text-to-speech module available at a monitoring station. Ongoing research on using RFID-embedded storybooks in educational contexts with deaf children is explored in greater detail in the work of Parton and Hancock (2011). Whenever deaf children scan the tags on the book's pages, a computer is triggered to play videos presenting a story in ASL. The research involving a prototype of this system yielded highly successful results, garnering overwhelmingly positive feedback from both teachers and the deaf students involved.

ADVANTAGES OF IOT FOR INDIVIDUALS WITH DISABILITIES

The IoT significantly benefits individuals with disabilities, enhancing mobility, communication, and functionality. Smart home systems and customized assistive devices improve the quality of life, enhancing independence (Shahrestani, 2017; Mohammed et al., 2020). IoT devices are revolutionizing health monitoring, navigation, education, and employment, promoting accessibility, customization, and social inclusion, and improving independence and quality of life for disabled individuals (Farahani et al., 2020; Abdelwahab et al., 2024). Creating inclusive environments that foster the participation and inclusion of individuals with disabilities in various aspects of life, including social, economic, political, and cultural domains, is a priority (Chadha et al., 2021; World Health Organization, 2022). The IoT significantly enhances inclusive environments for individuals with disabilities by improving access to buildings, transportation, information, and communication and enhancing independence and self-assurance (Lanigan et al., 2006; Ripat and Woodgate, 2011). IoT integration in shopping and smart homes fosters independence, reducing caregiver assistance and empowering individuals with disabilities. Home automation manages routine tasks, reducing caregiver assistance. IoT-facilitated interactive play environments benefit children with sensory or cognitive disabilities, enhancing their learning experiences, language acquisition, social skills, and self-esteem (Hengeveld et al., 2009; Hussien et al., 2020).

Additionally, these interactive IoT systems are designed to accommodate the individualized learning paces of these children. For instance, for deaf children with hearing parents unfamiliar with ASL, these systems provide additional exposure to facilitate their language acquisition process (Parton et al., 2009). Utilizing IoT-based interactive systems, these children can extend their learning experiences beyond the classroom, allowing them to revisit and reinforce challenging vocabulary until they fully comprehend and commit it to memory. This innovative and engaging approach to learning significantly enhances accessibility. It reduces learning barriers, which is particularly significant given the strong connection between early exposure to signed language and later academic achievement in deaf children (Parton et al., 2009).

CHALLENGES IN RESEARCH

The research challenges in implementing IoT for individuals with disabilities include customizing solutions, implementing intelligent workflows, and leveraging context-aware IoT-driven processes to make contextually informed decisions; despite the unique needs of this user group (Wieland et al., 2008), these workflows transform low-level contextual data into high-level business insights. Developers often employ business process modeling tools to define tasks within these intelligent workflows. Another notable framework, Presto, adopts a model-based approach (Giner et al., 2010) to capture the interactions between physical entities and their digital counterparts. The Presto architecture addresses the challenge of balancing the customization needs of individuals with disabilities while optimizing efficiency and usability in IoT-driven workflows. By enabling users to interact with the physical world, the system presents services based on their role and current tasks. This allows users to be steered through workflows tailored to their needs, such as library patrons using pathological demand avoidance (PDAs). The system also accommodates disabled users by automatically detecting returned books using RFID technology. The guidance for IoT solutions for individuals with disabilities includes providing visual or auditory information directions and facilitating access to amenities. However, self-management is a significant challenge, requiring self-configuration, self-healing, self-optimization, and self-protection to ensure an inclusive experience (Haller et al., 2009). Self-configuration and self-healing are key aspects of IoT technology, ensuring they adapt to different scenarios and requirements. Self-optimization focuses on automated monitoring and resource management, providing peak performance. Self-protection involves proactive identification and safeguarding of IoT systems, mitigating security threats. Self-healing is crucial for individuals with disabilities, as disruptions can impact

Table 2: The advantages and disadvantages of the IoT.

Advantages of IoT	Disadvantages of IoT
Enhanced connectivity: IoT enables seamless connectivity between devices, allowing for efficient data exchange and communication.	Security Concerns: IoT devices are vulnerable to cybersecurity threats, posing risks to privacy, data integrity, and system security.
Improved efficiency: IoT enhances operational efficiency by automating processes, optimizing resource utilization, and enabling real-time monitoring and control.	Complexity and interoperability issues: Managing diverse IoT devices and platforms can be complex, leading to interoperability and integration issues.
Cost savings: IoT technologies help organizations reduce costs through predictive maintenance, energy optimization, and streamlined operations.	Privacy Risks: IoT devices collect vast amounts of personal data, raising concerns about privacy infringement, data misuse, and unauthorized access.
Enhanced decision-making: IoT generates valuable insights through data analytics, enabling informed decision-making, predictive analytics, and trend analysis.	Limited standards and regulations: The absence of standardized protocols and regulations for IoT devices hinders interoperability, security, and compliance.
Remote monitoring and control: IoT enables remote monitoring and control of devices and systems, facilitating remote diagnostics, troubleshooting, and management.	Data overload and management: The proliferation of IoT devices generates massive volumes of data, posing challenges in data storage, processing, and analysis.
Innovation and business opportunities: IoT drives innovation and creates new business opportunities across industries, fostering product innovation, market expansion, and revenue growth.	Reliability and stability: IoT systems may encounter reliability issues, downtime, and performance bottlenecks, impacting service availability and user experience.

Abbreviation: IoT, Internet of Things.

daily lives. Research in IoT for disabled individuals faces various challenges such as customization, personalization, and accessibility standards. Developing flexible devices and interfaces and creating comprehensive guidelines are essential for ensuring usability and inclusivity. Integrating user-centered design principles, seamless interoperability, robust security measures, energy efficiency, affordability, and ethical considerations are crucial for the full potential of IoT technologies. These include involving people with disabilities in the design process, addressing privacy and security issues, focusing on energy-efficient designs, reducing production costs, providing adequate training, examining ethical frameworks, and staying updated on evolving regulations. These efforts are essential for fostering independence, inclusion, and accessibility in the lives of individuals with disabilities. Table 2 shows the advantages and disadvantages of the IoT.

CONCLUSION

This paper delves into the transformative potential of the IoT for individuals with disabilities, illuminating its capacity to foster enhanced independence and inclusivity. It meticulously examines the landscape of IoT applications tailored to meet the diverse needs of individuals with disabilities, from smart assistive devices to adaptive home automation systems. Furthermore, the paper navigates through the ongoing research challenges within this domain, meticulously addressing critical areas such as accessibility standards, user-centered design principles, technical barriers, affordability constraints, proper training, and ethical considerations surrounding data privacy and security. By spotlighting these challenges, the paper underscores the need for collaborative efforts among researchers, policymakers, and stakeholders to navigate and mitigate these complexities effectively. Despite the multifaceted hurdles, the paper remains optimistic, envisioning a promising future where IoT technologies seamlessly empower individuals with disabilities, fostering a more accessible and equitable world for all.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest in association with the present study.

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REFERENCES

Abdelwahab M.M., Al-Karawi K.A., Hasanin E. and Semary H. (2024). Autism spectrum disorder prediction in children using machine learning. *J. Disabil. Res.*, 3, 20230064.

Ahmad S. and Tokhi M.O. (2011). Linear quadratic regulator (LQR) approach for lifting and stabilizing of two-wheeled wheelchair. In: *2011 4th International Conference on Mechatronics (ICOM)*, Kuala Lumpur, Malaysia, 17-19 May 2011; pp. 1-6.

Alenizi A.S. and Al-Karawi K.A. (2022a). Cloud computing adoption-based digital open government services: challenges and barriers. In: *Conference Proceedings of Sixth International Congress on Information and Communication Technology: ICICT 2021*, Volume 3, Springer Singapore, London, pp. 149-160.

Alenizi A.S. and Al-Karawi K.A. (2022b). Internet of things (IoT) adoption: challenges and barriers. In: *Conference Proceedings of Seventh*

International Congress on Information and Communication Technology: ICICT 2022, Volume 3, Springer Nature Singapore, London, pp. 217-229.
Alenizi A.S. and Al-Karawi K.A. (2023a). Effective biometric technology used with big data. In: *Proceedings of Seventh International Congress on Information and Communication Technology*; pp. 239-250.
Alenizi A.S. and Al-Karawi K.A. (2023b). Machine learning approach for diabetes prediction. In: *International Congress on Information and Communication Technology*; pp. 745-756.
Al-Karawi K.A. (2021). Mitigate the reverberation effect on the speaker verification performance using different methods. *Int. J. Speech Technol*., 24, 143-153.
Al-Karawi K.A. (2023a). Face mask effects on speaker verification performance in the presence of noise. *Multimed. Tools Appl.*, 83, 1-14.
Al-Karawi K.A. (2023b). Real-time adaptive training for forensic speaker verification in reverberation conditions. *Int. J. Speech Technol.*, 26, 1-11.
Al-Karawi K.A. and Ahmed S.T. (2021). Model selection toward robustness speaker verification in reverberant conditions. *Multimed. Tools Appl.*, 80, 1-18.
Al-Karawi K.A. and Mohammed D.Y. (2019). Early reflection detection using autocorrelation to improve robustness of speaker verification in reverberant conditions. *Int. J. Speech Technol.*, 22, 1-8.
Al-Karawi K.A. and Mohammed D.Y. (2021). Improving short utterance speaker verification by combining MFCC and Entrocy in Noisy conditions. *Multimed. Tools Appl.*, 80, 22231-22249.
Al-Karawi K.A. and Mohammed D.Y. (2023). Using combined features to improve speaker verification in the face of limited reverberant data. *Int. J. Speech Technol.*, 26, 1-11.
Al-Karawi K.A., Al-Noori A.H., Li F.F. and Ritchings T. (2015). Automatic speaker recognition system in adverse conditions--implication of noise and reverberation on system performance. *Int. J. Inf. Eng. Electron. Eng.*, 5, 423.
Almusaed A., Yitmen I. and Almssad A. (2023). Enhancing smart home design with AI models: a case study of living spaces implementation review. *Energies*, 16, 2636.
Alsinglawi B., Elkhodr M., Nguyen Q.V., Gunawardana U., Maeder A. and Simoff S. (2017). RFID localisation for internet of things smart homes: a survey. *Int. J. Comput. Netw. Commun.*, 9(1), 81-99.
Amaral L.A., Hessel F.P., Bezerra E.A., Corrêa J.C., Longhi O.B. and Dias T.F. (2011). eCloudRFID–A mobile software framework architecture for pervasive RFID-based applications. *J. Netw. Comput. Appl.*, 34, 972-979.
Axelsson A.K., Imms C. and Wilder J. (2014). Strategies that facilitate participation in family activities of children and adolescents with profound intellectual and multiple disabilities: parents' and personal assistants' experiences. *Disabil. Rehabil.*, 36, 2169-2177.
Ayton L.N., Barnes N., Dagnelie G., Fujikado T., Goetz G., Hornig R., et al. (2020). An update on retinal prostheses. *Clin. Neurophysiol.*, 131, 1383-1398.
Bansal M. and Garg S. (2021). Internet of Things (IoT) based assistive devices, In: *2021 6th International Conference on Inventive Computation Technologies (ICICT)*, Coimbatore, India, 20-22 January 2021; pp. 1006-1009.
Bello O., Zeadally S. and Badra M. (2017). Network layer inter-operation of device-to-device communication technologies in Internet of Things (IoT). *Ad Hoc Netw.*, 57, 52-62.
Bhatnagar V., Chandra R. and Jain V. (2019). IoT based alert system for visually impaired persons. In: *Emerging Technologies in Computer Engineering: Microservices in Big Data Analytics: Second International Conference, ICETCE 2019*, Jaipur, India, 1-2 February 2019, Revised Selected Papers 2; pp. 216-223.
Boy G.A. (2017). *The Handbook of Human-Machine Interaction: A Human-Centered Design Approach*, CRC Press, Boca Raton, FL, USA.
Buckl C., Sommer S., Scholz A., Knoll A., Kemper A., Heuer J., et al. (2009). Services to the field: An approach for resource constrained sensor/actor networks. In: *2009 International Conference on Advanced Information Networking and Applications Workshops*, Bradford, UK, 26-29 May 2009; pp. 476-481.
Chadha S., Kamenov K. and Cieza A. (2021). The world report on hearing, 2021. *Bull. World Health Organ.*, 99, 242.
Chan M., Estève D., Escriba C. and Campo E. (2008). A review of smart homes—present state and future challenges. *Comput Methods Programs Biomed.*, 91, 55-81.
Chaudhari N., Gupta A. and Raju S. (2016). ALED system to provide mobile IoT assistance for elderly and disabled. *Int. J. Smart Home*, 10, 35-50.
Chien-Yu L., Chao J.-T. and Wei H.-S. (2010). Augmented reality-based assistive technology for handicapped children. In: *2010 International Symposium on Computer, Communication, Control and Automation (3CA)*, Tainan, Taiwan, 5-7 May 2010; pp. 61-64.
D'Atri E., Medaglia C.M., Serbanati A., Ceipidor U.B., Panizzi E. and D'Atri A. (2007). A system to aid blind people in the mobility: a usability test and its results. In: *Second International Conference on Systems (ICONS'07)*, Martinique, France, 22-28 April 2007; pp. 35-35.
Darianian M. and Michael M.P. (2008). Smart home mobile RFID-based Internet-of-Things systems and services. In: *2008 International Conference on Advanced Computer Theory and Engineering*, Phuket, Thailand, 20-22 December 2008; pp. 116-120.
Das R., Tuna A, Demirel S. and Yurdakul M.K. (2017). A survey on the internet of things solutions for the elderly and disabled: applications, prospects, and challenges. *Int. J. Comput. Netw. Appl.*, 4, 1-9.
Discant A., Rogozan A., Rusu C. and Bensrhair A. (2007). Sensors for obstacle detection-a survey. In: *2007 30th International Spring Seminar on Electronics Technology (ISSE)*, Cluj-Napoca, Romania, 9-13 May 2007; pp. 100-105.
Domb M. (2019). Smart home systems based on internet of things. In: *Internet of Things (IoT) for Automated and Smart Applications* (Ismail Y., ed.) IntechOpen, London-United Kingdom.
Domingo M.C. (2012). An overview of the Internet of Things for people with disabilities. *J. Netw. Comput. Appl.*, 35, 584-596.
Farahani B., Firouzi F. and Chakrabarty K. (2020). Healthcare IoT. In: *Intelligent Internet of Things: From Device to Fog and Cloud*; pp. 515-545.
Farahsari P.S., Farahzadi A, Rezazadeh J. and Bagheri A. (2022). A survey on indoor positioning systems for IoT-based applications. *IEEE Internet Things J.*, 9, 7680-7699.
Frontera W.R. (2012). The world report on disability. *Am. J. Phys. Med. Rehabil.*, 91, 549.
Fukasawa A.J. and Magatani K. (2012). A navigation system for the visually impaired an intelligent white cane. In: *2012 Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, San Diego, CA, 28 August 2012 - 1 September 2012; pp. 4760-4763.
Giannakas F., Troussas C., Krouska A., Voyiatzis I. and Sgouropoulou C. (2023). Blending cybersecurity education with IoT devices: a u-Learning scenario for introducing the man-in-the-middle attack. *Inf. Secur. J.: Global Perspect.*, 32, 371-382.
Giner P., Cetina C., Fons J. and Pelechano V. (2010). Developing mobile workflow support in the internet of things. *IEEE Pervasive Comput.*, 9, 8-26.
Gokhale P., Bhat O. and Bhat S. (2018). Introduction to IoT. *Int. Adv. Res. J. Sci. Eng. Technol.*, 5, 41-44.
Goldin-Meadow S. and Feldman H. (1975). The creation of a communication system: a study of deaf children of hearing parents. *Sign Lang. Stud.*, 8, 225-233.
Hafsi T. and Thomas H. (2005). The field of strategy: in search of a walking stick. *Eur. Manag. J.*, 23, 507-519.
Hakobyan L., Lumsden J., O'Sullivan D. and Bartlett H. (2013). Mobile assistive technologies for the visually impaired. *Surv. Ophthalmol.*, 58, 513-528.
Haller S., Karnouskos S. and Schroth C. (2009). The internet of things in an enterprise context. In: *Future Internet–FIS 2008: First Future Internet Symposium, FIS 2008*, Vienna, Austria, 29-30 September 2008, Revised Selected Papers 1; pp. 14-28.
Hengeveld B., Hummels C., Overbeeke K., Voort R., van Balkom H. and de Moor J. (2009). Tangibles for toddlers learning language. In: *Proceedings of the 3rd International Conference on Tangible and Embedded Interaction*; pp. 161-168.
Hollier S. and Abou-Zahra S. (2018). Internet of Things (IoT) as assistive technology: Potential applications in tertiary education. In: *Proceedings of the 15th International Web for All Conference*; pp. 1-4.
Hussain S., Schaffner S. and Moseychuck D. (2009). Applications of wireless sensor networks and RFID in a smart home environment. In: *2009*

Seventh Annual Communication Networks and Services Research Conference, Moncton, NB, Canada, 11-13 May 2009; pp. 153-157.

Hussien N., Ajlan I., Firdhous M. M. and Alrikabi H. (2020). Smart shopping system with RFID technology based on Internet of Things. *Int. J. Interact. Mob. Technol.*, 14, 17-29.

Ivanov R. (2010). Indoor navigation system for visually impaired. In: *Proceedings of the 11th International Conference on Computer Systems and Technologies and Workshop for PhD Students in Computing on International Conference on Computer Systems and Technologies*; pp. 143-149.

Ju J.S., Shin Y. and Kim E.Y. (2009). Intelligent wheelchair (IW) interface using face and mouth recognition. In: *Proceedings of the 14th International Conference on Intelligent User Interfaces*; pp. 307-314.

Karagiannis V., Chatzimisios P., Vazquez-Gallego F. and Alonso-Zarate J. (2015). A survey on application layer protocols for the Internet of Things. In: *Transaction on IoT and Cloud Computing*, Vol. 3; pp. 11-17.

Khan Y, Ostfeld A.E., Lochner C.M., Pierre A. and Arias A.C. (2016). Monitoring of vital signs with flexible and wearable medical devices. *J. Adv. Mater.*, 28, 4373-4395.

Kher Chaitrali S., Dabhade Yogita A., Kadam Snehal K., Dhamdhere Swati D. and Deshpande Aarti V. (2015). An intelligent walking stick for the blind. *Int. J. Eng. Res. Gen. Sci*., 3, 1057-1062.

Kim Y. and Smith D. (2017). Pedagogical and technological augmentation of mobile learning for young children interactive learning environments. *Interact. Learn. Environ.*, 25, 4-16.

Krahn G.L. (2011). WHO World Report on Disability: a review. *Disabil. Health J.*, 4, 141-142.

Krishna S., Balasubramanian V., Krishnan N.C., Juillard C., Hedgpeth T. and S. Panchanathan. (2010). A wearable wireless RFID system for accessible shopping environments. In: *3rd International ICST Conference on Body Area Networks*.

Kulyukin V. and Kutiyanawala A. (2010). Accessible shopping systems for blind and visually impaired individuals: design requirements and the state of the art. *Open Rehabil. J.*, 3, 158-168.

Lachtar A., Kachouri A. and Val T. (2017). Real-time monitoring of elderly using their connected walking stick. In: *2017 International Conference on Smart, Monitored and Controlled Cities (SM2C)*; pp. 48-52.

Lanigan P.E., Paulos A.M., Williams A.W., Rossi D. and Narasimhan P. (2006). Trinetra: assistive technologies for grocery shopping for the blind. In: *ISWC*; pp. 147-148.

Li B., Munoz J.P., Rong X., Chen Q., Xiao J., Y. Tian, et al. (2018). Vision-based mobile indoor assistive navigation aid for blind people. *IEEE Trans. Mob. Comput.*, 18, 702-714.

Lieberman A.M., Hatrak M. and Mayberry R.I. (2014). Learning to look for language: Development of joint attention in young deaf children. *Lang. Learn. Dev.*, 10, 19-35.

López-de-Ipiña D., Lorido T. and López U. (2011). Indoor navigation and product recognition for blind people assisted shopping. In: *Ambient Assisted Living: Third International Workshop, IWAAL 2011, Held at IWANN 2011*, Torremolinos-Málaga, Spain, 8-10 June 2011, Proceedings; pp. 33-40.

Marques P.J.A. (2023). BRAILLESHAPES: efficient text input on smartwatches for blind people.

Marquez J., Villanueva J., Solarte Z. and Garcia A. (2016). IoT in education: integration of objects with virtual academic communities. In: *New Advances in Information Systems and Technologies*; pp. 201-212.

Martin S., Kelly G., Kernohan W.G., McCreight B. and Nugent C. (2008). Smart home technologies for health and social care support. *Cochrane Database Syst. Rev.*, CD006412.

Mnati M.J., Chisab R.F. and Van den Bossche A. (2017). A smart distance power electronic measurement using smartphone applications. In: *2017 19th European Conference on Power Electronics and Applications (EPE'17 ECCE Europe)*; pp. P.1-P.11.

Mohammed D.Y., Al-Karawi K.A., Husien I.M. and Ghulam M.A. (2020). Mitigate the reverberant effects on speaker recognition via multi-training. In: *Applied Computing to Support Industry: Innovation and Technology: First International Conference, ACRIT 2019*, Ramadi, Iraq, 15-16 September 2019, Revised Selected Papers 1; pp. 95-109.

Mohammed D.Y., Al-Karawi K. and Aljuboori A. (2021). Robust speaker verification by combining MFCC and entrocy in noisy conditions. *Bull. Electr. Eng. Inform.*, 10, 2310-2319.

Mouha R.A. (2021). Internet of things (IoT). *J. Data Anal. Inf. Process.*, 9, 77-101.

Murray C.J., Lopez A.D., Black R., Mathers C.D., Shibuya K., Ezzati M., et al. (2007). Global burden of disease 2005: call for collaborators. *Lancet*, 370, 109-110.

Nandini A., Dwivedi A., Kumar N.A., Ashwin T., Vishnuvardhan V. and Guddeti R.M.R. (2019). Smart cane for assisting visually impaired people. In: *TENCON 2019-2019 IEEE Region 10 Conference (TENCON)*; pp. 546-551.

Narasimhan P. (2006). Assistive embedded technologies. *Computer*, 39, 85-87.

Parton B. and Hancock R. (2011). Interactive storybooks for deaf children. *J. Technol. Integr. Classroom*, 3, 61-66.

Parton B.S., Hancock R., Crain-Dorough M. and Oescher J. (2009). Interactive media to support language acquisition for deaf students. *J. Educ. Technol.*, 5, 17-24.

Parton B.S., Hancock R. and Mihir M. (2010). Physical world hyperlinking: can computer-based instruction in a K-6 educational setting be easily accessed through tangible tagged objects. *J. Interact Learn. Res.*, 21, 257-272.

Pei X.L., Wang X., Wang Y.F. and Li M.K. (2013). Internet of things based education: Definition, benefits, and challenges. *Appl. Mech. Mater.*, 411, 2947-2951.

Perera V., Ekanayake L., Bandara A., Shakya D. and Oruthota U.S. (2021). IoT based smart shopping system. In: *2021 10th International Conference on Information and Automation for Sustainability (ICIAfS)*; pp. 225-229.

Peschel J.M. and Murphy R.R. (2012). On the human–machine interaction of unmanned aerial system mission specialists. *IEEE Trans. Hum. Mach. Syst.*, 43, 53-62.

Ramlowat D.D. and Pattanayak B.K. (2019). Exploring the internet of things (IoT) in education: a review. In: *Information Systems Design and Intelligent Applications: Proceedings of Fifth International Conference INDIA 2018*, Vol 2; pp. 245-255.

Rghioui A. and Oumnad A. (2018). Challenges and opportunities of internet of things in healthcare. *Int. J. Electr. Comput. Eng.*, 8, 2753.

Richard E., Billaudeau V., Richard P. and Gaudin G. (2007). Augmented reality for rehabilitation of cognitive disabled children: a preliminary study. In: *2007 Virtual Rehabilitation*; pp. 102-108.

Ripat J. and Woodgate R. (2011). The intersection of culture, disability and assistive technology. *Disabil. Rehabil. Assist. Technol*., 6, 87-96.

Rose K., Eldridge S. and Chapin L. (2015). *The Internet of Things: An Overview*, The internet society (ISOC), Vol. 80; pp. 1-50.

Ruder M., Mohler N. and Ahmed F. (2003). An obstacle detection system for automated trains. In: *Proceedings of the IEEE IV2003 Intelligent Vehicles Symposium (Cat. No. 03TH8683)*; pp. 180-185.

Ruzaij M.F. and Poonguzhali S. (2012). Design and implementation of low cost intelligent wheelchair. In: *2012 International Conference on Recent Trends in Information Technology*; pp. 468-471.

Saaid M.F., Ismail I. and Noor M.Z.H. (2009). Radio frequency identification walking stick (RFIWS): a device for the blind. In: *2009 5th International Colloquium on Signal Processing & Its Applications*; pp. 250-253.

Sarkar P., Dewangan O. and Joshi A. (2023). A review on applications of artificial intelligence on bionic eye designing and functioning. *Scand. J. Inf. Syst.*, 35, 1119-1127.

Satoh H., Kawabata T. and Sankai Y. (2009). Bathing care assistance with robot suit HAL. In: *2009 IEEE International Conference on Robotics and Biomimetics (ROBIO)*; pp. 498-503.

Schwiebert L., Gupta S.K. and Weinmann J. (2001). Research challenges in wireless networks of biomedical sensors. In: *Proceedings of the 7th Annual International Conference on Mobile Computing and Networking*; pp. 151-165.

Semary H., Al-Karawi K.A. and Abdelwahab M.M. (2024). Using voice technologies to support disabled people. *J. Disabil. Policy*, 3, 20230063.

Shaha A., Rewari S. and Gunasekharan S. (2018). SWSVIP-smart walking stick for the visually impaired people using low latency communication. In: *2018 International Conference on Smart City and Emerging Technology (ICSCET)*; pp. 1-5.

Shahrestani S. (2017). *Internet of Things and Smart Environments: Assistive Technologies for Disability, Dementia, and Aging*, Springer.

Shiizu Y., Hirahara Y., Yanashima K. and Magatani K. (2007). The development of a white cane which navigates the visually impaired. In: *2007 29th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*; pp. 5005-5008.

Siregar V.M.M. and Siagian N.F. (2022). The implementation of fingerprint sensors for fingerprint reader prototypes using a microcontroller. *Internet Things Artif. Intell. J.*, 2, 47-59.

Stangl A.J., Kothari E., Jain S.D., Yeh T., Grauman K. and Gurari D. (2018). Browsewithme: An online clothes shopping assistant for people with visual impairments. In: *Proceedings of the 20th International ACM SIGACCESS Conference on Computers and Accessibility*; pp. 107-118.

Stefanov D.H., Bien Z. and Bang W.-C. (2004). The smart house for older persons and persons with physical disabilities: structure, technology arrangements, and perspectives. *IEEE Trans. Neural Syst. Rehabil. Eng.*, 12, 228-250.

Suresh S. and Sruthi P. (2015). A review on smart home technology. In: *2015 Online International Conference on Green Engineering and Technologies (IC-GET)*; pp. 1-3.

Tan L. and Wang N. (2010). Future internet: The internet of things. In: *2010 3rd International Conference on Advanced Computer Theory and Engineering (ICACTE)*; pp. V5-376-V5-380.

Tsatsou P. (2020). Digital inclusion of people with disabilities: a qualitative study of intra-disability diversity in the digital realm. *Behav. Inf. Technol.*, 39, 995-1010.

Vasco Lopes N. (2020). Internet of things feasibility for disabled people. *Trans. Emerg. Telecommun. Technol.*, 31, e3906.

Wieland M., Kaczmarczyk P. and Nicklas D. (2008). Context integration for smart workflows. In: *2008 Sixth Annual IEEE International Conference on Pervasive Computing and Communications (PerCom)*; pp. 239-242.

Wilson C., Hargreaves T. and Hauxwell-Baldwin R. (2017). Benefits and risks of smart home technologies. *Energy Policy*, 103, 72-83.

World Health Organization. (2022). *Global Report on Health Equity for Persons with Disabilities*, World Health Organization.

Yassein M.B. and Shatnawi M.Q. (2016). Application layer protocols for the Internet of Things: a survey. In: *2016 International Conference on Engineering & MIS (ICEMIS)*; pp. 1-4.

Ye J.H., Ryu S.B., Kim K.H. and Y. S. Goo. (2010). Retinal ganglion cell (RGC) responses to different voltage stimulation parameters in rd1 mouse retina. In: *2010 Annual International Conference of the IEEE Engineering in Medicine and Biology*; pp. 6761-6764.

Yu X. and Marinov M. (2020). A study on recent developments and issues with obstacle detection systems for automated vehicles. *Sustainability*, 12, 3281.