Article title: Internet of Things (IoT) about Disabilities: Disabilities in relation to the Internet of Things (IoT)

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Disabilities in relation to the Internet of Things (IoT)

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***Abstract*—** 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. It is striking that more than one billion individuals, encompassing adults and children, live with disabilities, constituting roughly 15% of the world's total population. This highlights the significant impact and importance of addressing issues related to disability inclusivity and support globally. Unfortunately, the lack of support services often results in disabled individuals becoming overly reliant on their families, leading to economic inactivity and social exclusion.

Nevertheless, the Internet of Things (IoT) holds promise in offering essential aid and encouragement, empowering them to enhance their quality of life and engage more actively in societal and economic spheres. This article explains how the Internet of Things can benefit individuals with disabilities. We introduce the suggested IoT framework to realize this goal, highlighting the interplay between its diverse components. We delve into distinct application scenarios to demonstrate how the IoT can address the unique requirements of people with disabilities. Moreover, this paper addresses critical challenges to be acknowledged and overcome when implementing IoT-based solutions.

Keywords*— *IoT Technology; disable People; Smart assistant; Application, voice recognition system

1. 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[1]. Through IoT-enabled assistive devices and applications, individuals with disabilities can gain increased independence, access to vital services, and improved overall quality of life [2]. 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[3]. 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[4].

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's crucial to address privacy and security concerns to protect the sensitive data collected by these devices[5].

Furthermore, ensuring that IoT solutions are designed with universal accessibility principles will create an inclusive and empowering environment for people with disabilities[6].

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 ITU internet reports, and possess digital identities [7]. By amalgamating the internet and emerging technologies such as Radio-frequency Identification (RFID)[8], 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 [9]. Fig.1. shows the IoT assistive technologies for people with disability

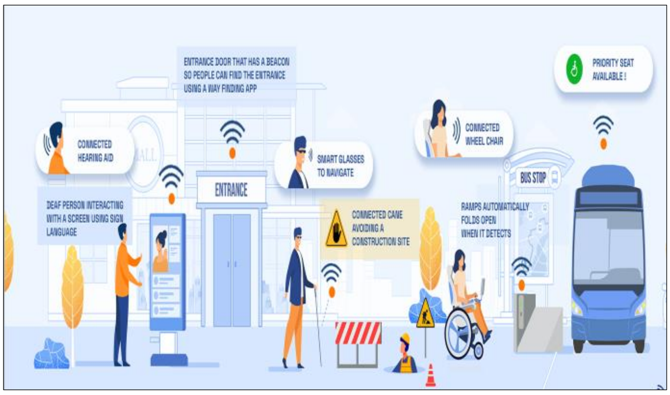

Fig.1. IoT assistive technologies for people with disability

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 [10-12], 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 [11].

According to the WHO report, within this demographic, 110 million individuals encounter substantial challenges in their daily functioning. Simultaneously, 190 million falls into the category of "severe disability," akin to conditions like quadriplegia, profound depression, or complete blindness [11, 13]. Furthermore, a recent 2010 study conducted by the Organization for Economic Co-operation and Development (OECD) shed 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 reveals that disabled individuals face an inactivity rate approximately 2.5 times higher than their non-disabled 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 reliance, in turn, obstructs their economic participation and social integration, limiting their opportunities for self-sufficiency and meaningful social involvement. We firmly advocate that the Internet of Things (IoT) holds the potential to offer invaluable assistance and support to individuals with disabilities, fostering an improved quality of life and active engagement in social and economic spheres. Integrating assistive IoT technologies is a potent means to enhance independence and facilitate increased involvement for people with visual, auditory, and physical impairments. This paper aims to comprehensively explore how individuals with disabilities, including those with visual, auditory, and physical impairments, can effectively engage with and benefit from IoT applications. Notably, this paper represents the pioneering effort in examining IoT solutions uniquely tailored to meet the needs of disabled individuals [2]. This paper presents an overview of the potential advantages of the Internet of Things (IoT) to individuals with disabilities. The paper is organized into the following sections: Section 2: Why focus on the IoT for people with disabilities, Section 3: IOT framework. Section 4: Application scenarios. Section 5: Advantages of IoT for individuals with disabilities. Section 6: Challenges in research. Finally, Section 7 is the conclusion.

2. WHY FOCUS ON THE IOT FOR PEOPLE WITH DISABILITIES

The Internet of Things (IoT) encompasses an ecosystem where applications and services rely on data collected from devices that interact with and sense the physical world. This vast network of connected devices continues to expand, offering various conveniences and lifestyle improvements, ranging from voice-activated assistants and health-monitoring devices to unconventional objects like dental floss and toothbrushes[1]. 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[2, 14]. The potential benefits of developing IoT devices and services tailored for people with disabilities hold tremendous significance, as they can significantly enhance their quality of life and open up new opportunities for accessibility and inclusivity[15]. The Internet of Things (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[14]:

- 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.Fig2. shows the control devices connected via smartphone applications

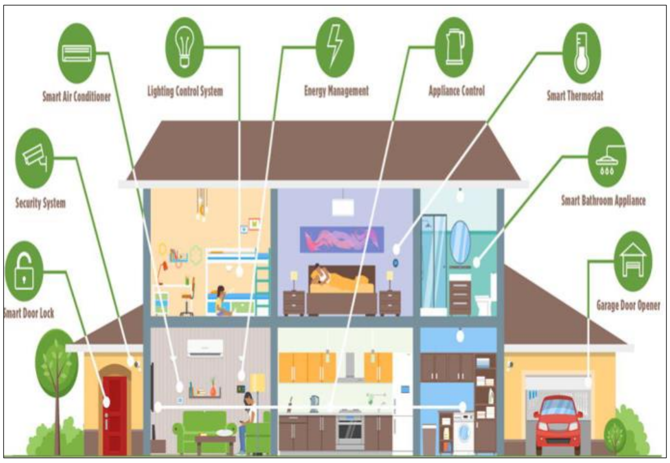

Fig.2. Control devices connected via smartphone applications

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[16]. 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[17].

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[18]. 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[19].

3. IoT Framework

Fig. 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 figure consists of three main layers:

A. *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[20].

- Visually impaired:

The components designed to aid the visually impaired consist of Body Micro and Nano Sensors. 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: These devices utilize radio-frequency identification (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:

The first category, Body Micro-and Nano-Sensors, refers to tiny sensing devices integrated into smart gloves, glasses, or canes. These sensors continuously monitor the environment, detecting obstacles, changes in terrain, or the presence of objects. The data collected by these sensors is 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 identity 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. devised a retinal prosthesis to regain vision for individuals afflicted with retinitis pigmentosa and age-related macular degeneration, two progressive conditions leading to blindness [20]. 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 [21]. The retinal prosthesis comprises a camera mounted on eyeglasses, transmitting image data to an implant connected to the retina. This implant consists of a cluster of micro-sensors within the body. It utilizes electrical impulses to activate the relevant ganglion cells, converting these impulses into neurological signals. These signals are subsequently conveyed through the optic nerve to the brain. This innovative method aspires to partially restore vision in individuals suffering from these degenerative diseases, providing optimism for enhanced visual perception and overall quality of life [22, 23]. Currently, scientists are advancing in the creation of a Nano-scale artificial retina. Nano Retina, an innovative initiative, is dedicated to developing the Bio-Retina project—a groundbreaking endeavor. This bio-inspired retina integrates numerous Nano-sized components into a tiny retinal implant, as depicted in Figure 4. The central aim of Bio-Retina is to substitute impaired photoreceptors within the eye with an advanced 5000-pixel (second-generation) retinal implant. This cutting-edge implant can transform naturally captured light into electrical signals, activating the neurons responsible for relaying the captured images to the brain. A specialized pair of activation eyeglasses is employed to power the Nano-sized components of the implant. These glasses work with the Bio-Retina, ensuring they receive the energy to function effectively. The development of Bio-Retina and its Nanoscale components marks an exciting advancement in vision restoration and offers promising possibilities for those affected by retinal damage. As research progresses, these groundbreaking technologies can revolutionize how we address vision impairments in the future[24].

- RFID-based assistive devices.

A crucial RFID-based application is the navigation system, which is particularly beneficial for aiding blind individuals in unfamiliar areas. This system employs RFID tags distributed throughout the area, strategically placed to guide and protect the blind person. For instance, RFID tags can be positioned at the center of sidewalks to provide orientation cues, allowing blind individuals to navigate safely without the risk of accidental falls near the sidewalk's edge[25, 26]. 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[27]. 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 encompasses the unique ID string associated with the tag [28, 29]. 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 [30, 31]. This RFID-based navigation system, integrated into the cane, enables a blind individual to receive real-time guidance, enhancing their autonomy and safety while exploring various locations. Combining RFID technology and voice-enabled directions significantly improves visually impaired individuals' overall mobility and independence.

The RFID cane can also incorporate an obstacle detection system utilizing an ultrasonic sensor. 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 [32]. The monitoring station processes this information and provides immediate feedback to the blind person. This feedback could be in the form of audible alerts or vibrations, warning the blind person about the presence of the obstacle and allowing them to adjust their path or take necessary precautions to avoid collisions. By combining RFID-based navigation with an obstacle detection system based on an ultrasonic sensor, the RFID cane becomes an even more effective tool for blind individuals, providing them with valuable real-time information about their surroundings and enhancing their confidence and safety during navigation[33, 34].

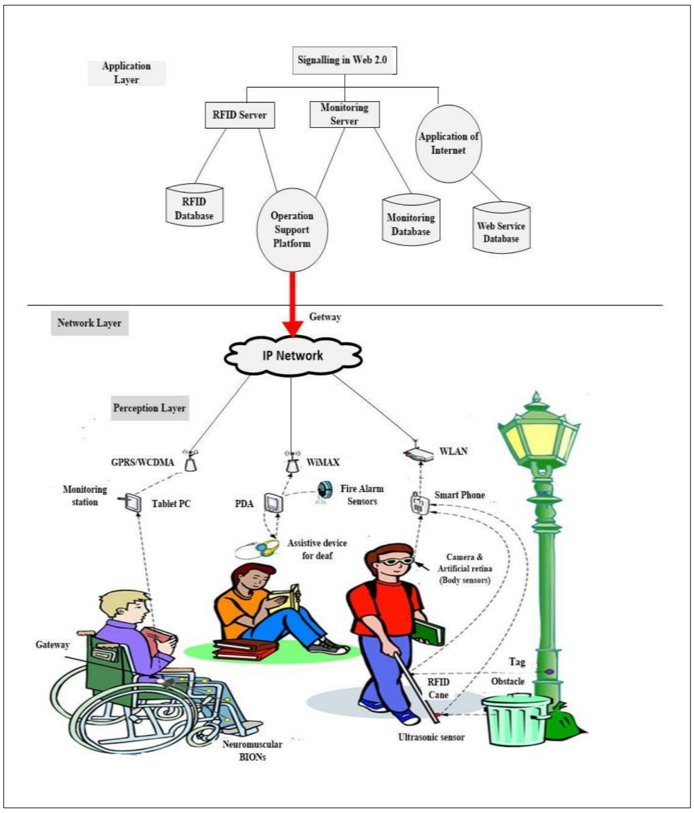

Fig. 3. Proposed Framework

This layer is at the bottom and represents the physical world where data is sensed and collected. It includes sensors, actuators, monitoring stations (e.g., smartphones, tablets, etc.), RFID tags, and readers/writers[20]. The Perception Layer captures data from the environment and feeds it into the IoT system. The Perception Layer provides contextually relevant information concerning the surroundings of people with disabilities. Its components are tailored to address specific disabilities such as visual impairment, hearing impairment, or physical impairment. The following are the descriptions of the components based on the disability of the person. For Visually Impaired Individuals, including Tactile Sensors, these sensors provide tactile feedback, enabling visually impaired individuals to navigate and interact with their surroundings through touch. In addition to delivering image recognition systems and using advanced image recognition technology, these systems help visually impaired individuals identify objects, texts, and obstacles in their environment[23].

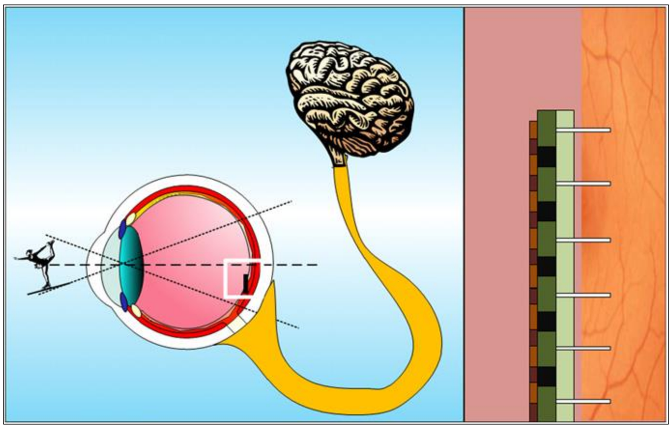

Fig.4. Positioning of the retinal implant(left); bionic chip and its interface with the retina(right).

Furthermore, for deaf individuals, the vibrating sensors convert auditory signals into vibrations, allowing deaf individuals to perceive sounds through touch. It also includes visual alerts, and this device with flashing lights or visual cues is used to notify hard-of-hearing individuals of sounds, such as doorbells or alarms. Moreover, Physically Impaired Individuals include motion sensors that detect movement and gestures, allowing physically impaired individuals to control devices and perform actions using gestures. It also includes robotic devices equipped with actuators, and AI algorithms assist physically impaired individuals in performing tasks like mobility support or manipulation of objects.

B. *Network Layer*

Located in the middle, the Network Layer is responsible for data transmission and communication. It encompasses wired and wireless networks, privately owned networks, the Internet, and network administration systems. This layer ensures seamless data exchange between devices and procedures within the IoT ecosystem. The network layer in the Internet of Things (IoT) is the backbone that enables the seamless communication of a vast array of devices and sensors. It encompasses a spectrum of communication protocols and technologies that facilitate the connection of IoT devices to networks, whether it's the Internet, local area networks (LANs), or wide area networks (WANs)[35]. These protocols, ranging from Wi-Fi and Bluetooth to cellular and Low-Power Wide-Area Networks (LPWANs), are chosen based on factors like range, power efficiency, and data requirements. At the heart of this layer lies the IP addressing, often powered by IPv6, which ensures that each IoT device can be uniquely identified on the internet, enabling direct communication. This layer also manages routing, forwarding, and mesh networking, ensuring data finds its way efficiently across a web of devices. Security is paramount here, with encryption, authentication, and authorization mechanisms safeguarding IoT data in transit. Scalability, quality of service, low-power considerations, and interoperability are among the other vital aspects handled by the network layer to ensure the IoT ecosystem functions reliably and securely, meeting the diverse needs of IoT applications[36].

C. Application Layer:

A layer represents the 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 Internet of Things (IoT) is where IoT systems' true value and functionality come to fruition[37]. It represents the topmost layer in the IoT architecture and is responsible for enabling specific applications and services that cater to various industries and use cases. At this layer, data collected from IoT devices is processed, analyzed, and transformed into actionable insights. Application layer protocols and APIs allow developers to create custom software applications, dashboards, and interfaces tailored to the unique needs of IoT deployments. These applications range from smart home automation and industrial monitoring to healthcare solutions and environmental sensing. Additionally, the application layer often incorporates machine learning and artificial intelligence algorithms to extract meaningful patterns and predictions from the vast amounts of IoT data generated. In essence, the application layer in IoT is where the real-world benefits, innovation, and customization of IoT technologies are realized [38].

4. APPLICATION SCENARIOS

Here, I present several application scenarios of the Internet of Things (IoT) specifically created to aid individuals with disabilities. These scenarios illustrate the smooth integration of diverse elements within the IoT framework.

4.1. A shop situation

The integration of IoT in shopping scenarios enhances customer convenience, optimizes store operations, and provides a more personalized and interactive shopping experience for all customers, including those with disabilities. In this scenario, visually impaired individuals can shop independently, as illustrated in Figure 6. The system employs blind navigation to help them find their way within a store. The store's RFID system uses software to assist visually impaired shoppers efficiently. In a study conducted by López-de-Ipiña et al., they introduced a navigation system based on RFID tags [39]. The supermarket is partitioned into cells, each comprising a shelf and passageway. RFID tags are dispersed across the floor, each with unique IDs linked to navigation data like cell type and adjacent cells. A smartphone-based monitoring system was established to assist visually impaired individuals during shopping trips. This system involves a monitoring station that maintains a Bluetooth connection with the user's RFID reader and a smart cane, enabling continuous tracking of the user's location by associating tag IDs with navigation information. The monitoring station has a speech synthesis and recognition module, allowing visually impaired users to specify the supermarket section they intend to visit. The system utilizes a WLAN connection to interact with web services on the Internet to determine the optimal route. As the user navigates the store, real-time routing instructions are received through an Android application and conveyed as voice messages through headphones connected to the smartphone. This real-time guidance ensures a seamless and independent shopping experience. The supermarket's products have RFID tags that provide crucial information such as product name, description, and price. Some RFID tags also incorporate sensors to capture additional data like temperature and transportation impacts. The RFID reader, the RFID cane, transmits the tag ID string to the monitoring station, which subsequently forwards this data to the RFID server. Product details are retrieved from the RFID database and relayed to the user as voice messages through the monitoring station.

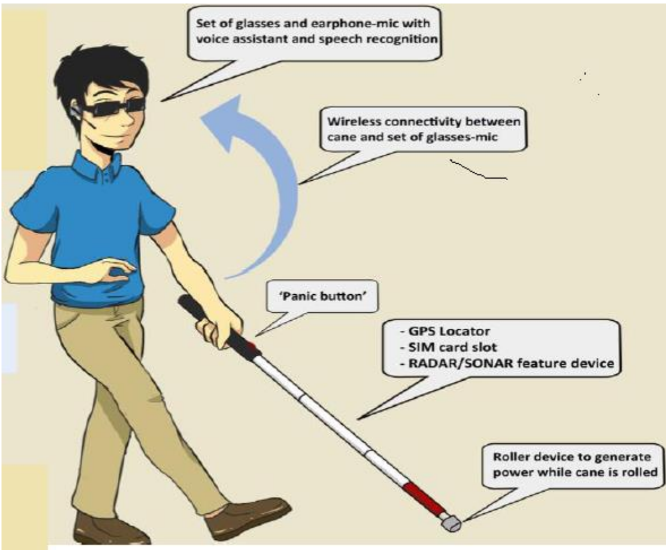

Fig.5 shows the smart cane.

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 [40]. 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 [41-43]. 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 [44, 45]. When individuals with visual impairments scan a grocery item using a portable barcode or RFID reader, the scanned data is 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 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 (UPC) or RFID database for additional information. The remote server or database takes the barcode or tag data and translates it into a user-friendly product name and relevant details, which are then transmitted back to the smartphone. Equipped with 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 [42, 44]. 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.

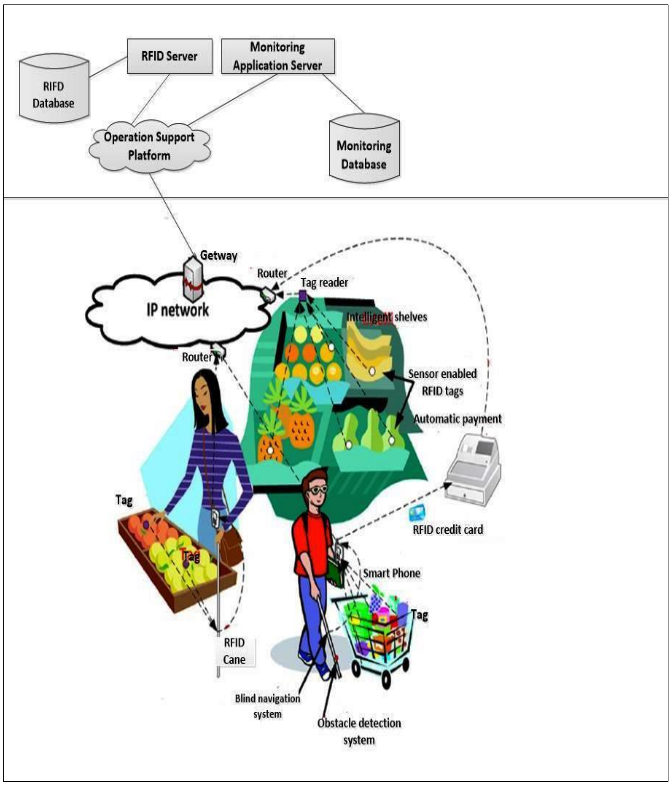

Fig.6 The shopping situation

4.1 Local environment

As shown in Fig 8, smart home technology 5 refers to a collection of interconnected devices, appliances, and systems within a household designed to enhance convenience, efficiency, security, and overall quality of life through automation and remote control. These devices can be controlled and monitored through a central hub or smartphone app, allowing homeowners to manage various aspects of their home environment, such as lighting, temperature, security cameras, door locks, entertainment systems, and more, from a single interface [46, 47]. The technology often utilizes sensors, Wi-Fi connectivity, and artificial intelligence to enable seamless communication and interaction between different devices, creating a more integrated and responsive living space [48]. 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[49]. Home automation and control systems encompass sensors and actuators seamlessly embedded with various household items, appliances, or furniture. These sensors actively monitor environmental conditions, process the gathered data, and communicate with other devices via wireless networks. The amassed data is relayed to a central server, which delivers pertinent services to the user. In situations necessitating alarm triggers, such as burglary or fire alerts, actuators come into play to respond promptly to ongoing emergencies. Top of Form Incorporating RFID technology within the smart home environment is vital in fulfilling identification and tracking objectives. Integrating RFID (Radio Frequency Identification) technology in the smart home environment represents a transformative advancement that seamlessly merges automation, security, and convenience. RFID's capability for efficient identification and tracking finds practical applications in various aspects of daily life within the home. The smart home can recognize and interact with them meaningfully by affixing RFID tags to objects, appliances, and even individuals [50]. This enables personalized experiences, such as automatic adjustment of lighting, temperature, and entertainment preferences as individuals move through different rooms. RFID's role in access control also ensures enhanced security, with keyless entry based on authorized user identification. The data insights from RFID-enabled devices further optimize resource usage and refine daily routines. Ultimately, integrating RFID technology augments the smart home's overall intelligence and responsiveness, redefining how we interact with and experience our living spaces[51]. Fig.7 shows the Smart watch for blind people.

Fig.7. Smart watch for blind people

In their study, Darianian and Michael introduced a master-slave RFID framework [52]. 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 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 president’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 [53].

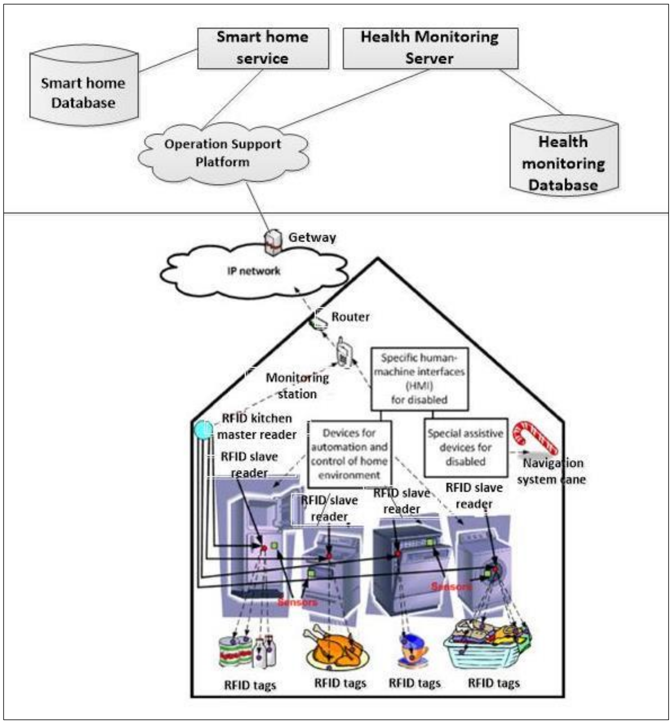

Fig8. The smart home situation

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[54].

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[55]. Smart homes are tailored to accommodate individuals with disabilities using two distinct approaches:(1) Customized interfaces are developed to streamline the operation of home automation and control devices. (2) 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 as follows, as elaborated in[49]

- Individuals with visual impairments necessitate a specialized Human-Machine Interface (HMI), which is a user interface designed to facilitate communication and interaction between humans and specific machines or systems, often tailored to

  Accommodate unique requirements and functionalities. Unlike generic HMIs, which serve a broader range of applications, specialized HMIs are crafted to meet the specific needs, tasks, and limitations of a particular domain, industry, or user group[56, 57]. An alternative approach to improve their vision is using retinal prostheses[20]. 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 [58, 59], 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 [58, 59]

  - Hearing-impaired people require:

  Specialized Human-Machine Interface (HMI): Utilizing touchscreens 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 serves as valuable assistance tools [25, 60]. Examples include powered wheelchairs and specialized lifting mechanisms designed to transfer users between beds and wheelchairs [61]. 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 HAL robot suit. These assistive devices may also integrate specialized Human-Machine Interfaces (HMIs) as needed, ensuring effective operation for individuals with disabilities[62].

4.3 At Education

Integrating the Internet of Things (IoT) into education revolutionizes traditional learning environments. In this dynamic scenario, classrooms are becoming smart and interactive, equipped with various connected devices. These devices, including interactive whiteboards, tablets, and sensors, empower educators to deliver more engaging and personalized lessons[63, 64]. 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[65].

Moreover, IoT enables remote learning, making education accessible to a broader audience, and plays a vital role in asset management and attendance tracking. By harnessing data generated from IoT devices, educational institutions can make data-driven decisions, fostering innovation and improving overall educational outcomes. However, as IoT adoption in education grows, it also necessitates careful consideration of data privacy and security to ensure that students and staff are protected in this digitally connected learning ecosystem[66, 67]. The illustration in Figure 10 depicts a school scenario. Their research underscores the substantial benefits of creating intelligent interactive play and educational environments tailored for toddlers one and a half to four, particularly those with multiple disabilities [67]. These systems aim to enhance their language and communication abilities. These play and learning environments utilize RFID (Radio-Frequency Identification) technology to identify different objects, including children's toys like sheep [68].

Moreover, RFID-tagged toys assist deaf children aged three to four in learning sign language[69]. The software allows a child to use an RFID reader to scan an item's tag, capture its distinctive identification number, and send it to the computer's software via a USB connection. An animation is initiated, featuring videos of a person and an avatar. In Figure 10, we observe education. as demonstrated by Hengeveld and colleagues [68], underscoring the significant advantages of creating intelligent interactive play and learning environments tailored for toddlers aged one and a half to four years old, especially those with multiple disabilities. These innovative systems are specifically crafted to boost their language and communication capabilities. These play and learning systems integrate RFID (Radio-Frequency Identification) technology to recognize various objects, including a child's toys, such as a sheep.

Furthermore, RFID-tagged toys are instrumental in aiding deaf children aged three to four in learning sign language, as elaborated in[68], emphasizing the substantial benefits of developing intelligent interactive play and learning environments for toddlers aged one and a half to four years old, particularly those with multiple disabilities. These innovative systems are designed to enhance their language and communication skills. These play and learning systems incorporate RFID (Radio-Frequency Identification) technology to identify various objects, such as a child's toys, like a sheep.

Additionally, RFID-tagged toys assist deaf children aged three to four in learning sign language, as detailed by[69-71]. 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 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 or 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 9 illustrates the finger reader.

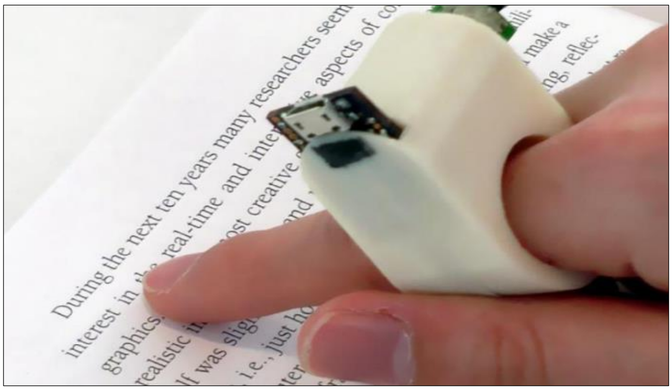

Fig.9. Finger Reader

This approach also entails presenting the concept in written English, fostering a bilingual approach to language acquisition. To assess the influence of this technology on vocabulary acquisition, the system was incorporated into the early childhood curriculum at the Louisiana School for the Deaf for four weeks, yielding favourable outcomes [72]. Furthermore, the research conducted by Parton and colleagues [69] 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 to 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 accessible 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.

Additionally, this concept extends the application of the technology to visits to zoos or farms, where children equipped with tag readers and monitoring stations can engage in experiential learning with real objects (e.g., a genuine apple or elephant instead of plastic replicas). The tag reader would transmit the tag ID string of the scanned item to the monitoring station, which would then relay this information to the RFID server. Details about the scanned object are retrieved from the RFID database and transmitted to the monitoring station, triggering the playback of a multimedia video. Augmented Reality (AR) is a technology that merges real-world and computer-generated environments. AR relies on tags, a web camera, and image processing equipment. A computer program is activated to recognize actual AR objects and acquire their tag IDs. The program can present the objects on the screen, play real-time audio files, and more. For instance, picture cards can incorporate AR tags. The AR image processing equipment identifies the picture card when it appears on the screen and uses the tag to identify the card type. This results in introducing corresponding sounds, such as a ringing telephone, creating an amalgamation of virtual sound with real imagery[73].

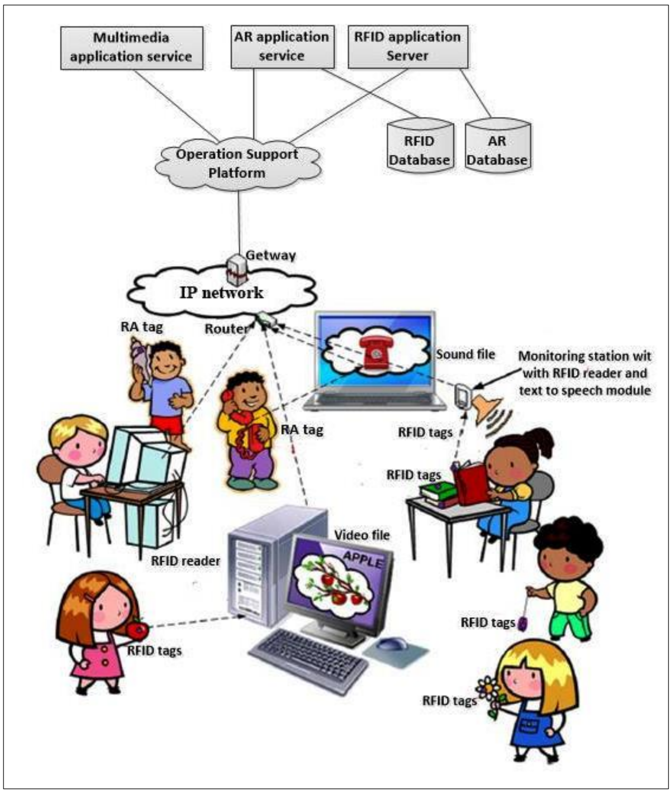

Fig.10.Education scenario

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 [73, 74]. Research involving young children with physical disabilities, ranging from kindergarten to first grade, has consistently shown that Augmented Reality (AR) is a remarkably efficient assistive technology. AR applications have also been developed to engage children in interactive experiences with 2D and 3D representations of various plant elements, including fruits, flowers, leaves, and seeds [75]. In this interactive setup, children are tasked with physically reaching for and manipulating a designated object, typically found on a physical marker, to place it in a specific location guided by the Augmented Reality (AR) system's instructions. The system employs various sensory cues to aid them in making correct decisions. These cues include visual cues, such as objects encircled by red or blue rings indicating correct or incorrect placement, auditory cues where the object's name is audibly announced and even olfactory cues related to the object's scent.

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 [76]. Whenever deaf children scan the tags on the book's pages, a computer is triggered to play videos presenting a story in American Sign Language (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.

5. ADVANTAGES OF IOT FOR INDIVIDUALS WITH DISABILITIES

The benefits of the Internet of Things (IoT) for individuals with disabilities are substantial and far-reaching. IoT technologies empower people with disabilities to lead more independent lives by providing tools and devices that enhance mobility, communication, and overall functionality. Smart home systems enable greater autonomy, allowing individuals to control their environment easily. IoT-driven assistive devices, such as smart wheelchairs and communication aids, are customized to cater to specific needs, improving the quality of life for those with disabilities[6]. Health monitoring through IoT devices ensures timely medical attention, and navigation aids assist in safe mobility. IoT fosters inclusive education through interactive learning tools and provides employment opportunities through remote work options. By promoting accessibility, customization, and social inclusion, IoT is revolutionizing how individuals with disabilities interact with the world, offering them greater independence and an improved quality of life [77]. 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 (World Health Organization[12, 78]. Creating inclusive environments for individuals with disabilities is greatly facilitated by the Internet of Things (IoT). IoT is pivotal in aiding people with disabilities, including establishing access to buildings, improving transportation, enabling information access, and enhancing communication. In this discussion, we will explore the distinct advantages of IoT for individuals with disabilities, with a particular emphasis on the application scenarios mentioned earlier. In contexts like smart homes or shopping scenarios, IoT streamlines daily tasks for impaired individuals, ultimately boosting their independence and self-assurance. For visually impaired individuals, achieving independence in daily duties without relying on sighted assistance is paramount [45, 79]. The integration of IoT into shopping processes enables them to shop independently, meeting these critical needs.

Furthermore, smart homes play a significant role in fostering independence concerning mobility, object manipulation, and human-machine communication interfaces. Through home automation, various routine tasks, like controlling lighting, are seamlessly managed, effectively reducing or eliminating the need for caregiver assistance. This, in turn, empowers individuals with disabilities to lead more self-reliant lives. Conversely, children with sensory or cognitive disabilities can benefit from interactive play and learning environments facilitated by IoT, as demonstrated in the school scenario. Such environments enhance the learning experiences of individuals, reducing the development of cognitive skills, expanding opportunities for language acquisition, promoting the growth of social skills, and, as a result, significantly bolstering their self-esteem [68, 80].

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 American Sign Language, these systems provide additional exposure to facilitate their language acquisition process [72]. 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 [72].

6. CHALLENGES IN RESEARCH

Moving forward, let's explore some of the research challenges associated with the implementation of IoT for individuals with disabilities. One prominent challenge lies in customizing IoT solutions to meet the unique needs of people with disabilities. Considering this user group's specific and diverse requirements, tailoring IoT technologies to suit their circumstances becomes essential. The customization process heavily relies on implementing intelligent workflows and context-aware IoT-driven processes. These workflows can make contextually informed decisions by leveraging data collected from the environment through various sensors. As explained in[81], 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 [82] to capture the interactions between physical entities and their digital counterparts. However, it's worth noting that in deploying these business models in an execution engine, human intervention may still be required to complete certain tasks within the workflow. Balancing the customization needs of individuals with disabilities while optimizing the efficiency and usability of these IoT-driven workflows presents a significant research challenge in this domain. The architecture of Presto effectively addresses these demands by providing mechanisms that enable users to interact with the physical world, ensuring their active participation in the process. This system is adept at presenting services to each participant based on their role and current tasks within the physical environment. As a result, users are steered through workflows meticulously customized to meet their requirements. For example, let's take the case of a library patron with a monitoring station, like a Personal Digital Assistant (PDA), upon entering the library premises. In this particular situation, the Presto system promptly presents the user with a list of tasks that can be initiated and accomplished, considering the available task processors. It's worth noting that the system accommodates the requirements of users with disabilities. For instance, if a disabled user selects the 'return book' option, the return boxes in the library, equipped with RFID technology, automatically detect returned books. Presto offers various ways to guide users to the nearest return box, considering their disability. This guidance extends to various forms, such as offering visual or auditory information, providing directions for individuals with mobility limitations, and facilitating access to areas where amenities like return boxes are situated. This approach ensures an inclusive and accessible experience for all. Another noteworthy challenge when implementing IoT solutions for individuals with disabilities is self-management. In this context, self-management pertains to IoT's capacity to oversee its operations autonomously without continuous human intervention. To accomplish this, it demands the incorporation of a range of self-management capabilities, including self-configuration, self-healing, self-optimization, and self-protection, as emphasized in the work of [83]. Self-configuration pertains to the automatic configuration of IoT components, ensuring they seamlessly adapt to different scenarios and requirements. Self-healing involves the IoT's capacity to autonomously detect and rectify faults or issues that may arise during operation. This aspect holds paramount significance since individuals with disabilities frequently depend on IoT devices to address their unique requirements. The concept of self-optimization centers on automated monitoring and resource management, aiming to guarantee peak performance in alignment with predefined criteria. This facet is indispensable in ensuring the delivery of dependable and consistent services. Furthermore, the facet of self-protection deals with the proactive identification and safeguarding of IoT systems, mitigating potential security threats and attacks. This proactive security approach is crucial in maintaining the integrity and functionality of these systems. Among these capabilities, self-healing is particularly crucial for individuals with disabilities, as any disruption in IoT functionality can significantly impact their daily lives. Therefore, robust mechanisms for swiftly detecting and addressing faulty nodes and the design of efficient fault-tolerant algorithms are essential to ensure the uninterrupted operation of IoT solutions tailored to the unique requirements of people with disabilities. Research in the field of IoT for individuals with disabilities faces several critical challenges that demand innovative solutions. First and foremost is the need for customization and personalization. Disabilities vary greatly, and IoT technologies must be adaptable to meet the unique needs of each individual. This involves developing flexible devices and interfaces that can be adjusted according to user-specific requirements. Ensuring accessibility standards is another paramount challenge. Researchers must create comprehensive guidelines and standards to guarantee that IoT technologies are usable and inclusive for disabled individuals. Moreover, user-centered design principles should be integrated, involving people with disabilities in the design process to ensure these technologies meet their needs. Interoperability is a significant technical challenge, as IoT devices often come from various manufacturers and use different communication protocols. Ensuring seamless integration and interaction between these devices is crucial for creating functional ecosystems. Privacy and security issues are also paramount, given the sensitive data collected and transmitted by IoT devices. Research must focus on robust security measures and privacy controls to safeguard users' data and privacy. Energy efficiency is another concern, particularly for battery-powered assistive devices. Research efforts should explore energy-efficient designs and power management solutions to prolong usage periods. Affordability remains a challenge, as IoT technologies should be accessible to individuals with disabilities across various socioeconomic backgrounds. Reducing production costs and exploring funding models for affordability are areas where research can make a substantial impact. Additionally, providing adequate training and education on IoT device usage is essential. Developing accessible training materials and methods empowers individuals with disabilities to maximize the benefits of these technologies. Ethical considerations surrounding data collection, consent, and potential discrimination in IoT applications require careful examination. Developing ethical frameworks and guidelines for IoT in disability contexts is essential. Lastly, researchers must keep abreast of evolving regulations and advocate for comprehensive accessibility standards to ensure IoT solutions remain compliant and beneficial in the long term. Addressing these research challenges is crucial to harnessing the full potential of IoT technologies for enhancing the lives of individuals with disabilities fostering independence, inclusion, and accessibility.

7. CONCLUSION

In summary, exploring the Internet of Things (IoT) in the context of individuals with disabilities presents a significant potential for transforming the lives of those confronting distinct challenges. The investigation of tailored and individualized IoT solutions offers the prospect of enhanced independence and inclusivity. This paper has provided a comprehensive overview of the IoT's applications for individuals with disabilities, shedding light on its promising future implications. It delves into pertinent application scenarios and highlights the significant benefits derived from these IoT solutions. Additionally, the paper conducts a comprehensive survey of the ongoing research challenges in this field, emphasizing that these research issues present ample opportunities for future investigations and technological advancements. Pursuing accessibility standards and user-centered design principles ensures these technologies truly cater to the diverse needs of users with disabilities. Overcoming technical hurdles, such as interoperability, privacy, and energy efficiency, remains pivotal in delivering reliable and secure IoT experiences. Moreover, addressing affordability concerns, providing proper training, and adhering to ethical considerations are integral aspects of this transformative research. As we navigate these multifaceted challenges, we unlock a world of opportunities to enhance the lives of individuals with disabilities, empowering them to lead more independent, fulfilling, and inclusive lives through the potential of the Internet of Things. The future of IoT for individuals with disabilities is not just promising; it is a beacon of progress towards a more accessible and equitable world.

Conflicts of interest

The authors declared no conflict of interest

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