BRIDGING THE ACCESSIBILITY GAP: SMART HOME INNOVATIONS FOR VISUALLY IMPAIRED INDIVIDUALS

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ABSTRACT: In this paper we explore how smart home technologies can better serve visually impaired individuals, focusing on the importance of intuitive user interfaces and assistive tools. While smart homes offer great convenience, many designs fail to consider the needs of those with visual impairments. With more than 2.2 billion people worldwide experiencing some form of visual impairment, making smart home systems inclusive is crucial. This study looks at existing technologies such as voice assistants and haptic feedback, highlighting the need for user-friendly and adaptable interfaces. It also points out gaps in current research and stresses the importance of creating standardized guidelines to improve accessibility, ultimately aiming to enhance the quality of life and independence for visually impaired users.

KEYWORDS: *Smart Home; Visual Impairment; Accessibility; User Interface (UI), User Experience (UX)*

1.0 INTRODUCTION

A smart home is a house equipped with sensors that monitor activity and controls the house through several services including lights and appliances, energy management and even monitoring the activities of residents. It is a convenient home system where appliances and devices are automatically controlled by remotely from anywhere via internet connection by anyone [1]. Smart home brings comfort to its end user where users can control and monitor devices through mobile devices, personal computers, and others. These systems come with their own user interface and user experience systems, most of the systems are not optimized for visually impaired people.

Currently, at least 2.2 billion people in the globe with some visual impairments [2-3]. Visual impairment impacts peoples social, physical and emotional wellbeing. It leads to a restriction in all aspects of daily living and quality of life [2]. Ensuring visually impaired people can access the benefits of smart home systems is a challenge. An intuitive and usable user interface is a crucial point of smart home systems [2].

Studies show that age-related macular degeneration, cataracts, diabetic retinopathy are likely to affect people with age [4]. A mentionable percentage of people suffer from some kind of visual impairment from early in their life and population growth and aging are expected to increase the number of patients upcoming days. Visual impaired persons tend to be older, less economically well-off, and more socially isolated.

Research in this area can help empower the targeted population to interact with their environment effectively, regardless of the disabilities they would be able to get benefits from the systems. Accessible, intuitive, and scripted organized home features improve the quality of living and independence of individuals. Individuals can enjoy autonomy and social participation by getting the power to control appliances on their own.

The rest of the article is structured as follows. Section II introduces the methodology of this study. Then, we present the results and discussions in Section III and Section IV respectively. Lastly, Section V covers the conclusion.

2.0 METHODOLOGY

The methodology used in this study is described as follows.

Literature search: A comprehensive search of databases including IEEE, ACM, Google Scholar for keywords like "smart home", "assistive technology", "accessibility", "UI/UX" and "visual impairments" was applied. Related webpages were also studied.

Inclusion and exclusion criteria: We considered insights from studies published during 2014-2024, included journal articles, conference papers and relevant industry reports, webpages for visually impaired users. Papers published in other languages and not specifically related to visual impairment were excluded.

Data extraction: We selected information from each study focusing on types of technology discussed for visually impaired people, UI/UX design considerations, proposed solutions and their effectiveness. We used the data to identify the common themes, trends and potential gaps in the area focusing on usability of smart home systems for visually impaired users. All the studies were selected based on relevance to the topic. This methodology helped us to get insights from the existing papers and identify the key problems and potential gaps.

3.0 RESULT

In this section, we present the outcomes of our analysis of the related works. Voice control smart home has been proposed in [5] where impaired persons can control their home appliances through voice commands. The research project achieved 96.74% accuracy with a good acceptance rate. The work in [6] evaluated multimodal user interface (MUI) and Smart Home (SH) application using voice commands as well as hand gestures. This model uses deep learning methods that perform better than existing solutions. The model showed 83.74% accuracy in detecting the command of users.

We observe a variety of innovative accessory devices like smart cane. The cane vibrates and send audio messages to users if it detects any obstacles within its range [7]. We found graphical user interface are mostly usable, it enhances convenience, whereas voice interface lacks feedback informativeness and is suitable for control. Also, chatbots are faster in executing operations [8]. Related work in [9] focused on simplifying UI components on smartphones and smartwatches for visually impaired people. The study involved forty-nine blind participants who evaluated the blind-friendly interface on smartphones and smartwatches. This study showed simplifying and spreading User Interface Artefacts (UIAs) across various devices had a positive effect on the usability and accessibility of visually impaired individuals.

Through the review process, we discovered that although there are several existing research studies and solutions, there are no standardized guidelines for designing assistive technologies. Different impairment groups require specific types of technology, highlighting the lack of universally accepted solutions.

4.0 DISCUSSION

Currently, some research exists on the usability for visually impaired people of smart home systems including UI/UX, accessible displays, voice control appliances, braille labeling, text-to-speech and audio feedback, smartphones, and wearable integrations [10]. A study by Cherpet Tshuma (2022) shows the psychological challenges that visually impaired people face including low self-esteem, loss of self-worth, and emotional distress. The are physical challenges like frequent falling while moving, taking help from others, and mobility issues [11]. People with these impairments are more prone to frequent anxiety compared to the general population.

A usability study of tactile and voice interaction modes was conducted by Vigouronux et al [12]. They used a seventy square meter apartment with various IoT equipment that is voice and touch-enabled. They studied behaviours and need of population affected by different disabilities. Participants in this experiment faced many difficulties while interacting with the devices. This study focused on the usability of different home automation systems. The study shows the need for multimodality and customizations needed in smart home interfaces.

Voice control smart home has been proposed in [13] where impaired persons can control their home appliances through voice commands. They used some template matching algorithm to recognize speech, and voice captured into the microphone was analysed and converted into signals using a pre-exiting TTS database. The signals give controls over electrical appliances through relay module. The research revealed that voice control systems can enhance the convenience of visually impaired persons. Table 1 shows the related technology requirements.

Table 1: Technology requirements by impairments group [12]

Participant	Age/genre / Impairment		Activities	Technology needs for smart home
101	63/M	Hearing impairment	Pharmacist, now retired	adapted intercom with high quality visuals to see the person and read their lips ; connected objects with visual feedback; flashing lights; app on phone to detect someone's presence or an abnormal noise.
102	72/M	Visual impairment	Computer science now retired	easy to implement; efficient and responsive technology, limit the number of steps, preference for voice control with voice feedback on actions performed; home automation control (shutters, light, alarm) but with reliability and ease of use.
104	39/F	Cerebral palsy	Employee in an association and volunteer	interfaces for home automation control (shutters, front door); voice control difficult in case of fatigue, so have the touch mode; connected intercom without the need to pick up the phone.
202	18/M	Trisomy syndrome	Student	smartphone application to help organise activities, to encourage initiatives (coaching application).
204	19/M	Cerebral palsy	Student	smartphone control system for gates, garages and front doors to be autonomous; smartphone remote control for TV, robotic arm.
300	38/F	Myopathy	Volunteer	home automation to control the environment (with voice command); robotic arm (help for cutting, grabbing objects, grooming), adapted intercom (easy to open and to communicate).
302	70/F	Polio	Secretary, retired and volunteer	opening of the gate from your home; automated bay window; automation control of equipment for individual and mobile homes; fall detector or easy emergency call.

Alsaif and Albarrak [6] model, which employs deep learning methods, demonstrated superior performance compared to existing solutions. The use of deep learning significantly enhanced the accuracy of the system. They experimented using both voice and image datasets. The dataset had 29,444 samples with 20 commands audio sets, and 2000 samples of facial recognition. Multimodal system proved to be the most effective system comparing with other solutions. The model was compared with existing solutions those were using different systems and data fusion modals. They compared their system with other data fusion methods including facial expressions, head and body movements, video data, and others.

Many innovative devices are available to help visually impaired individuals navigate, such as smart canes that can detect obstacles ahead. The cane vibrates and send audio messages to users if it detects any obstacles within its range. Ultrasonic and infrared sensors are used to detect obstacles from a further distance up to a 2-meter radius. They utilized Raspberry Pi, Python language, and Android phones to illustrate the project. The researchers also mention the use of camera integration that can make it further effective [7].

A study in [14] explores the connection of home appliances to an embedded controller that can receive commands through gestures. The proposed system utilizes the MPU 6050 sensor for gesture control. Using relays, the systems connect and control electronic appliances. The system is a cost-effective system available for visually impaired persons, it offers home monitoring through voice and gesture control. While there is research on how smart home systems can take commands from individuals who are struggling with visions.

There are also researches related to how user interfaces and user experience settings can be optimized for targeted groups of people. We found out home graphical user interface are mostly usable. It enhances convenience, the voice interface lacks feedback informativeness and is suitable for control. Also, chatbots are faster in executing operations. The research used a survey method for evaluating the methods currently available. The study compared the graphical user interface, voice, and messenger interfaces. They further evaluated web interface, mobile app interface, chatbot, voice assistance with phone application by success rate, execution time and user satisfaction score [8].

A study was conducted on UX and UI analysis for some common and specialized applications, a simple analysis showed poor colour contrast in Google Maps, and inconsistent font sizes in WhatsApp and Gmail conversations. The study identified weaknesses in commonly used apps designed for visually impaired individuals. It proposed solutions such as audio descriptions, captions, and transcripts as alternatives. Additionally, enhancing the color contrast and increasing the size of icons could potentially improve usability for the visually impaired [15].

Khan and Khusro (2022)[16] focused on simplifying UI components on smartphones and smartwatches for visually impaired people. The study involved forty-nine blind participants who evaluated the blind-friendly interface on smartphones and smartwatches. The study targeted groups by disabilities and their appropriate accessibility features. Table 2 summarizes the details. The research described in [17] demonstrates the effectiveness of customized interfaces in enhancing user satisfaction and reducing cognitive load. It proposes a hardware and software architecture that enables alarm notifications for events. The paper suggests integrating both visual and audio systems to improve accessibility.

Many articles are being written related to the design of UI for visually impaired persons. Exploring the diverse range of impairments and unique needs with unique challenges and solutions, for example, limited vision users, and color blindness. Some tools are proposed to be used as audio descriptions, keyboard only, magnification, refreshable braille display, screen reader, and so on. Certain shapes, and colors to convey messages are effective[18].

One of the available apps dedicated only to visually impaired people is "Be My Eyes". This app connects low vision to totally blind users online with a virtual assistant via video call. Through the video call, volunteers help visually impaired people with visual assistance by telling them about their surroundings that can be seen on the camera. Visual-impaired users can request free help by making a call. Currently, there are 662,742 visually impaired users who are taking help in 180+ languages from 7,547,838 volunteers around the world. The recent integration of Open AI has taken the app further, now the users can point their cameras to get visual insights from AI [19]. Table 3 summarizes the related works.

Table 2: Current available accessibility features in smartphones and watches for target groups [16]

Feature	Android	iOS	Dependency	Devices	Target Group	Purpose
Screen reader	Yes	Yes	User	Smartphone/ smartwatch	Blind people/ visually impaired people	Device navigation
Zooming	Yes	Yes	User	Smartphone/ smartwatch	Low vision	Display customization
Large TEXT	Yes	Yes	User	Smartphone/ smartwatch	Low vision	Magnification
High Contrast	Yes	Yes	User	Smartphone	Low vision	Display customization
Basic/full/ HTML web browser support	Yes	Partial	User	Smartphone	Low vision/blind people	Text-to-speech, Display Navigation, Surfing
Accessibility API	Yes	Partial	Device	Smartphone	Blind/low vision	All
Haptic feedback	Yes	Yes	User	Smartphone/ smartwatch	Blind people	Device Navigation, Display Customization
Keyboard support	Yes	Yes	Device	Smartphone	Blind people	Text-Entry, Display Customization
Field navigation	Yes	Yes	User	Smartphone/ smartwatch	Blind people	Device navigation. Display Customization
Sound back	Yes	Yes	User	Smartphone/ smartwatch	Blind people	Display Customization, display navigation
Gesture support	Yes	Yes	User	Smartphone/ smartwatch	Blind People	Display Customization, display navigation

Table 3. Literature review conclusions related to accessibility of visual impaired

Author (Year)	Reference	Methods used	Conclusions
Sankar et al. (2023)	[14]	Gesture control system with relay connections	Cost effective solution for independent living, enhanced convenience
Chuan et al. (2022)	[13]	Template matching algorithm, voice captured by microphone then sent as digital signal.	Proposed Voice control systems for visual impaired, accuracy 96.74% with 79.33 % acceptance rate.
Khan and Khusro (2022)	[16]	Empirical study on blind people for user interface evaluation	Simplified UI components improve task completion, it reduces cognitive loads, increases user satisfaction
Micovic et al. (2022)	[9]	Creation of smart home rules	Discussed about smart home automation triggers, actions, rules
Vigouroux et al. (2022)	[12]	Experiment in smart home by participating visual impaired persons, used USE and UEQ questionnaires to assess usability	Participant found tactile and voice commands most useful, also need for customizable and easy to use interface systems
Veigl et al. (2022)	[20]	Participatory research design with blind and visually impaired experts	High usability when visual, auditory and haptic feedback are available
Qaiser et al. (2021)	[21]	A SLR to identify relevant articles, keywords and design thinking process for visually impaired individuals	Disaggregated disabilities need divers solutions for visually impaired individuals, more research should be facilitated
Alsaif and Albarrak (2020)	[6]	MUI using ML	Proposed model achieved 83.74 accuracy, surpassing other models significantly.
Arugollu et al (2018)	[15]	Alternative text objects, audio, captions, font styles for legibility	Revealed poor colour contract in google maps, inconsistent font sizes in WhatsApp and Gmail, accessibility features can benefit in economy.
Ciabattoni et al. (2018)	[17]	hardware architectures with sensors, cloud servers, smartphone	Proper designed user interface helps visually and hearing impaired individuals.
Adigun et al. (2014)	[2]	Cross sectional studies with 375 patients, questionnaire by family physicians	Visual impairments life the quality of life, more in older patients, cataracts, glaucoma, refractive errors are common causes of visual impairments

5.0 CONCLUSION

Numerous articles and research efforts have addressed challenges faced by individuals with visual impairments, ranging from advancements in voice commands, gestures, and facial recognition to innovations like smart cane sticks and intuitive user interfaces for smart devices. However, our review identified significant gaps. Variations in impairment types necessitate tailored solutions, yet current smart home systems often overlook these diverse needs. The absence of standards and guidelines, coupled with insufficient research in this area, complicates these challenges. Solutions frequently lack integration for multimodal user interfaces (MUIs), and voice assistance features often lack user-friendly feedback. Specific gesture designs remain underexplored, highlighting key areas for future research. Further investigation into impairment types is essential to determine optimal solutions. Establishing guidelines and frameworks for UI/UX design is imperative for addressing these issues. Thus, continued research aims to achieve Sustainable Development Goals (SDGs), particularly in promoting good health and well-being for visually impaired individuals.

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