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Revolutionizing Accessibility: Smart Wheelchair Robot and Mobile Application for Mobility, Assistance, and Home Management

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Abstract—**This research aims to advance accessibility and inclusivity for individuals with disabilities. We focus on specific daily challenges facing people with disabilities in communication, mobility, and daily task management and introduce AssistEase, a groundbreaking smart wheelchair solution designed to empower people with disabilities by improving mobility, communication capabilities, and daily task management. AssistEase will contribute to the disabled community around the world by allowing them to manage daily tasks and communicate more easily while ensuring mobility. AssistEase offers control options such as hands-free voice control, traditional manual control, smartphone-based Bluetooth control, or innovative gesture control, designed to cater to different user preferences and needs. This uses technologies such as speech recognition, computer vision, and haptic [92] feedback to help users navigate safely while avoiding obstacles. It integrates technologies like Flutter, TensorFlow, YOLOV8, Global Positioning System (GPS), Bluetooth, and Apple Home Kit, along with hardware components including Arduino and Raspberry PI. Preliminary trials have shown improvements in mobility, communication, and daily tasks for users in need. It achieves 95% precision in guiding wheelchair users while maintaining about 90% accuracy for the robotic arm and 89% for health monitoring and location tracking. Also, it provides a user-friendly app with 90% control accuracy. The communication device has 92% accuracy in facilitating user communication, while hand gesture control achieves 90% accuracy. To advance AssistEase smart wheelchair technology, further research, and development are required to enhance its adaptability for specific disabilities. AssistEase reflects a commitment to creating a more inclusive and thriving society, focusing on innovation and inclusion for individuals of all abilities.**

Keywords*—*Convolutional Neural Network (CNN); Deep Learning (Dl); Global Positioning System (GPS); Smart Home Management; Cutting-Edge Technologies; Voice Control; Remote Monitoring; Accessibility; Inclusivity; Assistive Technology; Disability Support.

I. INTRODUCTION

Assistive products such as wheelchairs help improve the health, well-being, participation, and inclusion of people with disabilities. Wheelchairs provide an independent life of dignity for children, adults with disabilities, and older people. It opens the door to education, employment, and social engagement for children and adults living with disabilities. There are approximately 240 million disabled children worldwide [1].

Many people experience permanent or temporary disabilities due to accidents or illnesses, which can significantly affect their mobility and independence. Wheelchairs have become a necessity for those who face challenges with walking or vision. However, for some, operating a wheelchair independently can be challenging or even impossible, leading to reliance on others for mobility assistance.

According to the Fig. 1, there are one billion adults and children with disabilities that require assistive technologies, impacting their independence, education, and economic opportunities. This lack of access strains communities, resulting in caregiving burdens and perpetuating inequalities. Reports from WHO and UNICEF indicate that over 2.5 billion people need assistive technologies, and this issue becomes more pressing as the global population ages and noncommunicable diseases rise, with an estimated 3.5 billion individuals needing assistive products by 2050 [2].

Smart wheelchairs have emerged as a potential solution, but they may not be suitable for all individuals. For example, those who are mute cannot use voice commands, while people who are blind may struggle with the control of the mobile app. Additionally, amputees may find joystick control difficult.

Furthermore, the prolonged use of wheelchairs can lead to health concerns such as pressure sores and reduced physical activity. Blind and amputee people cannot switch on lights since they can stand, walk, or have vision problems. Those who are deaf, mute, or blind need a communication method to communicate with others as inhabitants of the world since we focus on individuals with disabilities as they encounter numerous challenges.

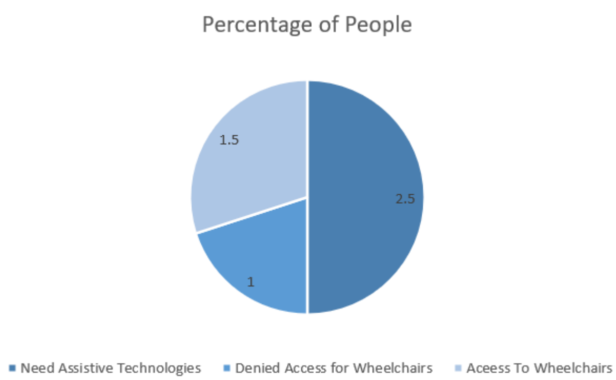


Fig. 1. Percentage of the People Who Need Assistive Technologies

As a solution, the AssistEase project stands as a pioneering research initiative that aims to address the unique needs of the community. The primary objective of AssistEase is to improve accessibility and inclusivity for people with disabilities by using technology by designing and integrating a smart robot wheelchair, incorporating a feature-rich communications device, and developing two mobile applications for communication and wheelchair control that collectively empower people with disabilities to enjoy efficient and independent mobility, thus improving their quality of life and overall inclusivity in society. In parallel, AssistEase develops a tailored software application that seamlessly complements the hardware, resulting in an enhanced user experience. 'AssistEase' ensures that this solution is efficient, user-friendly, and capable of addressing a wide range of challenges faced by individuals with disabilities.

AssistEase's smart wheelchair offers a versatile array of user control options to accommodate a wide range of disabilities and user preferences. These options include voice commands for people with physical disabilities and blind individuals, manual control, gesture-based input for mute individuals, and Bluetooth connectivity for extra robustness. This diversity in control mechanisms ensures that people with different needs can operate the wheelchair comfortably and effectively. The system's GPS location feature helps users navigate their surroundings with ease. Integration with smart home technology via the inbuilt braille keyboard for blind individuals through the Apple Home Kit and Siri virtual assistant enables automated control of the user's home environment, further enhancing their independence. This technology uses computer vision, speech recognition, and tactile haptic feedback to assist users in reaching their destinations safely while avoiding obstacles. It not only simplifies communication and navigation but also empowers individuals, offering them greater opportunities for self-sufficiency and an improved quality of life.

Most existing smart wheelchair applications mainly focus on helping users move around and avoid obstacles, but there is a need for applications that can provide a more interesting and personalized experience. The AssistEase application provides individuals with disabilities with a reliable, user-friendly, and accessible mobility solution with additional features such as real-time tracking, remote control, and health monitoring, enabling users to access the full range of functionalities of the smart wheelchair. Allow users to control the wheelchair using their mobile device, offering an additional level of convenience and accessibility. Additionally, it will provide users with a platform to communicate with the smart wheelchair, enabling them to give voice commands and navigate the device.

There are several key challenges addressed by AssistEase, one of which is communication, specifically in the context of understanding sign language by capturing the images and translating them into voice and text inputs through the communication mobile application, which will be invaluable for mute individuals who are limited to wheelchairs. By utilizing advanced deep learning techniques like convolutional neural networks (CNN), 'AssistEase' excels in identifying and recognizing hand motions, facilitating seamless sign language communication.

The AssistEase research contribution of the AssistEase project is its holistic approach to improving the lives of individuals with disabilities. By addressing mobility, communication, and accessibility, this initiative significantly contributes to the advancement of assistive technology, fostering independence, inclusivity, and enhanced quality of life for people with disabilities.

II. Literature Survey

The system survey includes data from various sources, such as websites and IEEE research papers. We explored major electronic sources such as IEEE Xplore and Google Scholar to gather information before conducting this systematic review. The inclusion criteria prioritized journal papers over conference proceedings by the same authors and only considered English-language works published between 2018 and 2023. After reviewing the titles and abstracts, the full texts of selected studies were examined to ensure that they met the inclusion criteria. This mainly focuses on assistive technology, particularly smart wheelchairs, which play a crucial role in enhancing mobility and independence for individuals in different activities such as movement, social interaction, and traveling.

The main aim of the study conducted by Zhang, Liu, Li, et al., published in Volume 7 on pages 23551–23562 in 2019 [3], is to create a smart wheelchair that can be controlled by the individual using it through different head gestures. The suggested wheelchair module includes unique characteristics that will make moving around more convenient and comfortable. According to various head gestures, an accelerometer has been used to operate the wheelchair in five directions. To position the wheels differently, two direct current (DC) motors have been added. Using Relay as the motor driver, the direction is controlled using an Arduino UNO. The wheelchair is solar-powered, putting the focus on the use of green energy. When there is insufficient light, the user can move with the aid of a light-dependent resistor (LDR) light-detecting sensor. For secure movement, a seat belt sensor has been used as a switch. To make movement safer, an ultrasonic sensor has been used as an obstacle detector.

The study by P. Shafiabady and F. Kiani, published in Volume 16, Issue 11, pages 4509–4513 in 2019 [4], discusses the development of a smart wheelchair that can be controlled using multiple controllers. With the help of a joystick and keypad module, this smart wheelchair can be controlled, along with an eye blink sensor for a quadriplegic patient. The use of other sensors, such as heartbeat sensors and temperature sensors, that monitor the user's health. For the convenience of the user, an indicator of urine level is also utilized. A fall detection system in the wheelchair detects the same if the patient falls while in it. If the patient falls while in the wheelchair, a fall detection system in the chair recognizes the same. In an emergency, the information can be shared with the hospital and the user's guardian. The design of this system places a high focus on the user's and the wheelchair's safety regarding the use of solar power.

In the study conducted by T. A. Alharthi, H. B. Ahmed, and Y. M. Sami, titled ”Smart irrigation system using the Internet of Things,” which was published in IEEE Access, Volume 8, on pages 171931 to 171942 in the year 2020 [5], a smart voice-controlled, completely automated wheelchair is created for physically disabled individuals, including pregnant women. They may easily move from one location to another. This system enables the user to actively communicate with the wheelchair in several control directions, such as turn left, turn right, move forward, go back, and stop. To develop the wheelchair, this project uses motor drivers and a microcontroller circuit.

In the report authored by H. Zhang, X. Shen, Y. Zhao, and Y. Sun, published in IEEE Access, Volume 9, on pages 481–489 in the year 2021 [6], the focus is on a smart city system that relies on the Internet of Things (IoT) and cloud computing and provides a cost-effective smart wheelchair based on IoT technology and an Arduino Nano-micro controller. It helps assist in completing everyday tasks without the assistance of others. Through the completion of the project, a variety of disabled people will be able to buy smart wheelchairs, especially those who are unable to afford expensive ones. The main components that powered this wheelchair are an ESP12e module for Wi-Fi access, the Arduino Nano, an MPU6050, obstacle detection, and joysticks used for wheelchair control.

In the study conducted by Y. Zhou, X. Li, and M. Yin, published in Volume 17, Issue 5, on pages 3344–3352 in 2021 [7], they developed a smart wheelchair equipped with two distinct driving systems: one based on gestures and the other controlled by thumb movements. The user may quickly navigate the menu and select their chosen control system because of the user interface (UI) design. To measure the user's medical conditions, a heart rate sensor is used. A built-in response mechanism will activate in the event of an emergency and notify the person who must be aware.

In the study by M. A. Khan, A. Hussain, M. Z. Iqbal, S. Ahmad, S. S. Raza, and M. Q. Islam, published in 2019 on pages 47–52 [8], the researchers present a model for a wheelchair that can be controlled by the brain. This model aims to assist patients who are disabled or paralyzed. The electroencephalogram (EEG) signals, commonly known as brain waves, are used to operate the wheelchair. In the EEG method, an electrode cap is placed on the user's scalp to collect EEG data. These signals are recognized and converted into motion commands that operate the wheelchair by the Arduino microcontroller. An Arduino-based robot is used to create the suggested wheelchair, and it is controlled by a user's brain waves via a BCI (brain-computer interface). A Neurosky MindWave headset is used to record human brain waves. The healthcare sector could be significantly impacted by the proposed wheelchair. The use of this brain-controlled wheelchair can enhance a disabled patient's quality of life.

In the study authored by S. S. Raza, S. Ahmad, M. A. Khan, and A. Hussain, published in IEEE Access, Volume 8, on pages 41304 to 41313 in 2020 [9], they introduced a method for controlling a smart wheelchair using gestures. This research-based initiative focuses on creating an intelligent Internet of Things and gestures that can be controlled by user-hand gestures. The customized smart wheelchair may move forward, right, left, and stop depending on the hand motion commands that are given to the system. If the user ever experiences a difficulty, problem, or urgent situation, or needs someone urgently, a single tap on the sensor will also help to send an emergency Short Message Service (SMS) to pre-selected emergency contacts; however, the smart wheelchair can be stopped by simply double tapping the sensor. Here, the prototype gadget is put to the test in-depth, and the results are significant enough to be provided in the section on result analysis.

In a study conducted by S. Wang, Z. Wu, and Y. Liu, which was published in the book ”Advances in Intelligent Systems and Computing,” Volume 858, on pages 63–70 in 2019 [10], they created a smart wheelchair with the goal of enhancing the quality of life for individuals with physical disabilities. This is a voice-controlled smart wheelchair equipped with improved functions, including line following with obstacle avoidance, voice control, and electric power. The integrated Automatic Voltage Regulator (AVR) micro-controller AT-mega328 control unit also includes the Global System for Mobile Communication (GSM), Bluetooth, infrared and ultrasonic sensors, and an LM35 temperature sensor.

In the study conducted by X. Zhang, Z. Li, and W. Wang and published in IEEE Access, Volume 8, on pages 2394–2404 in 2020 [11], they introduced a wheelchair that can be controlled through voice commands. This design aims to make it easier for users to operate the wheelchair with less effort. This enables people with disabilities to complete daily tasks on their own indoors. The five modules that make up the suggested approach are speech recognition, obstacle avoidance, autonomous navigation, health monitoring, and a central system controller. Manual mode and autonomous mode are the two operating modes for the wheelchair.

In the domain of technology and research, a range of articles contribute to diverse areas of interest. The first article [81] introduces an innovative smart home management system driven by IoT smart lighting, emphasizing efficiency and energy conservation through data collected from various sensors. It also showcases a real-world implementation. The second article [82] explores IoT and low-cost implementations for smart home automation, discussing technology choices, challenges, and benefits, with a case study demonstrating a cost-effective smart home automation system. The third article, [83], delves into the impact of intelligent speech recognition (ISR) systems on English learning, presenting a study affirming the enhancement of English listening and speaking skills among Chinese students. The article [84] [98] [100] proposes a lightweight API-based approach for flexible clinical NLP systems, aiming to simplify the development and deployment of clinical NLP systems, accompanied by a case study on adverse drug event identification. The final article [85] delves into the technical considerations of using oligonucleotide solution APIs, pivotal in synthesizing DNA or RNA strands for diverse applications, providing an extensive overview of available APIs and essential technical aspects for their use. Each article addresses unique technological challenges and solutions, contributing to the ever-evolving landscape of technology and research.

Alhamazani et al.'s (2021) literature review [19] offers an extensive and current assessment of the latest developments in the realm of hand gesture recognition and segmentation utilizing depth cameras. The authors delve into the diverse range of depth cameras available, the various techniques employed for feature extraction and classification, and the performance outcomes achieved across different datasets. Their overall conclusion underscores the substantial potential of depth cameras for enhancing the precision and resilience of hand gesture recognition and segmentation systems. Nevertheless, they astutely acknowledge the existence of persisting challenges that demand further consideration and resolution in this evolving field. In the context of sign language recognition, Martinez-Martin and Morillas-Espejo's (2021) paper [12] provides a thorough exploration of deep learning techniques for Spanish Sign Language (SSL) interpretation, offering valuable insights but with a significant limitation in its narrow focus on SSL, potentially hindering its transferability to other sign languages. In contrast, Yigzaw, Meshesha, and Diriba (2022) [13] present a notable approach for Amharic Sign Language (ASL) recognition, demonstrating the effectiveness of convolutional neural networks (CNNs) with a high accuracy of 95%. However, the absence of a comprehensive comparative analysis with other ASL recognition systems leaves questions regarding its broader applicability and competitiveness. Zheng et al. (2020) [14] propose a transformer-based sign language translation model for Chinese Sign Language with an impressive 92% accuracy, yet a more in-depth exploration of the inherent complexities and limitations of sign language-to-text translation is warranted. Gao et al.'s (2023) paper [15] introduces a novel approach using Wi-Fi signals for multitask sign language recognition in Chinese Sign Language, but a fuller discussion of the environmental constraints and Wi-Fi signal limitations is needed for real-world implementation. Mannan et al. (2022) [16] achieve an exceptional 97% accuracy in Chinese sign language recognition through hyperparameter optimization, yet a deeper dive into the computational demands and training resources required is necessary for a comprehensive assessment of practicality. AL Moustafa et al. (2023) [17] present an integrated approach combining Mediapipe with a CNN model for Arabic Sign Language (ArSL) recognition, offering promise in its combination of hand landmarks and CNN-based classification. However, a more thorough examination of system limitations and scalability for diverse sign languages would enhance the paper's broader relevance. Each paper makes valuable contributions to sign language recognition, but a more nuanced discussion of their limitations and applicability beyond their specific contexts would strengthen their impact.

Recent research in smart wheelchairs and mobility solutions covers a wide range of topics, including control mechanisms, health monitoring and emergency systems, sustainable energy sources, obstacle detection systems, user interfaces, shared control systems, data collection and analysis, vocational rehabilitation, and assistive mobility for children. Control mechanisms are being investigated for a variety of input modalities, including gestures, joysticks, eye-tracking, voice commands, and brain-computer interfaces. Some studies incorporate health monitoring features like heart rate sensors and emergency systems for fall detection and communication with hospitals or guardians. Additionally, there is a focus on sustainable energy sources like solar power and obstacle detection systems using sensors. Some studies aim to create cost-effective solutions for a broader user base, while others explore user interfaces and accessibility. Shared control systems, data collection and analysis, vocational rehabilitation, and assistive mobility for children are also areas of research. However, research gaps exist in evaluating the effectiveness of control mechanisms, enhancing health monitoring and emergency systems, assessing the sustainability of green energy solutions, improving obstacle detection and avoidance, investigating the economic viability of cost-effective solutions, optimizing user interfaces, exploring shared control systems' applications, and utilizing data collected for practical purposes. Furthermore, research is needed to assess the impact of advanced mobility solutions on vocational rehabilitation and workspace mobility and to understand the long-term effectiveness of assistive mobility solutions for children with disabilities, particularly in terms of skill development, independence, and quality of life. Addressing these gaps is essential for developing more effective and inclusive smart wheelchairs and mobility solutions.

The overall AssistEase project addresses four main objectives. Firstly, the project aims to design and develop a state-of-the-art smart robot wheelchair tailored to cater to the specific needs of individuals with disabilities, providing them with efficient and comfortable mobility assistance. In conjunction with this, the second objective involves the creation of a feature-rich communications device that seamlessly integrates with the smart wheelchair, enhancing the user's ability to interact with their surroundings.

Thirdly, efforts are directed towards the development of two mobile applications. The first application will not only connect with the communication devices but also allow for comprehensive control and customization of the wheelchair's features. Lastly, the fourth objective ensures that the smart robot wheelchair and its accompanying mobile app are seamlessly integrated, forming a cohesive ecosystem that empowers individuals with disabilities to travel with ease and independence.

III. RESEARCH GAP

The world of technology presents significant challenges for wheelchair users, many of whom struggle to adapt to new technological advancements, while others may be accustomed to these challenges. It is crucial for designers and architects to thoroughly understand and address every aspect of the users' needs. Considering the severity of these issues [66], [67], [68], it is crucial to provide solutions that can assist wheelchair users in becoming comfortable with technology and satisfy their fundamental demands for operating applications. This involves designing applications that are accessible to users with diverse needs.

Additionally, incorporating additional features that promote ease of use can significantly improve the user experience and alleviate the challenges faced by wheelchair users, ultimately uplifting their well-being. There are many health monitoring research works conducted by many researchers in many countries [44], [45], [74], [75], [76].

1) Wheelchair Robot: A lot of research has focused on helping people with disabilities move around, and smart wheelchairs have been developed using various technologies and tools. When we look at the studies, they categorize navigation methods into three groups based on how much assistance they provide [18], [20], [21], [101]. These groups are shared control, fully autonomous, and semi-autonomous control.

The advantage of semi-autonomous and fully autonomous systems is that when the user gives a command, they can relax since the navigation happens automatically and they only need to step in occasionally. With shared control, users have more independence because they can guide the wheelchair's motion and map out the path themselves. The smart wheelchair primarily focuses on handling emergencies or necessary actions, like avoiding collisions, steering around obstacles, or following walls.

Users provide short-term local destination instructions to semi-autonomous devices. The wheelchair then starts moving until an external navigation system confirms whether the instruction has been followed or not. Semi-autonomous systems can be especially helpful for individuals who are blind. In contrast, in an autonomous system, users can simply select their desired destination, and the wheelchair's navigation system takes full control of the route and navigation, requiring mapping and position-tracking techniques.

Many researchers have developed wheelchairs for helping patients [22], [23], [24], [25], [93], [94]. A very comprehensive analysis of the wheelchair review was completed by many researchers. Some voice-based control wheelchairs were developed by researchers with some intelligence [26].

Smart wheelchairs, as shown in Table I, which are some studies previously done on smart wheelchairs, can be considered as mobile robots with seats or else as specially motorized wheelchairs equipped with a control system and intelligent navigation methods, alongside various sensors that play crucial roles. These sensors allow the system to adapt to changes in the environment or the user's condition, and they can also facilitate patient monitoring systems, making them significant enhancements.

Additionally, incorporating warning devices is essential for safety. The development of the "AssistEase" smart wheelchair was meticulously guided by a user-centered approach, with a keen focus on incorporating feedback and addressing the needs of individuals, especially those with disabilities.

Advanced features such as various control options, a robotic arm, location tracking, and health monitoring were not mere technical additions; they were thoughtfully integrated based on user insights. The planning phase established a modular framework that allows users to customize the wheelchair's features to suit their specific needs.

TABLE I. SUMMARY OF RESEARCH GAP OF SMART WHEELCHAIRS

Research Study	Key Findings	Research Gap
Development of a Smart Wheelchair for Mobility Assistance [30]	Smart wheelchairs improve mobility for users with limited physical abilities.	Lack of research on user-centered design and intuitive control interfaces for smart wheelchairs.
Integration of Voice Control in Wheelchair Navigation [31]	Integration of voice control for wheelchair navigation. Improved accessibility for users with speech impairments. Limited exploration of real-time voice recognition challenges.	Research needed to address the reliability and real-time performance of voice recognition systems in smart wheelchairs.
Energy Efficiency in Smart Wheelchair Design [32]	Energy-efficient design considerations in smart wheelchairs. Use of lithium-ion batteries for longer operational time. Lack of standardized testing methods for energy consumption.	Research gap in developing standardized testing methods for assessing and comparing the energy efficiency of different smart wheelchair models.
"Safety Mechanisms in Autonomous Smart Wheelchairs [33]	Implementation of safety mechanisms such as collision avoidance. Improved user safety during navigation. Lack of comprehensive studies on safety in crowded or dynamic environments.	Research gap in evaluating the safety and collision avoidance algorithms of smart wheelchairs in complex, real-world scenarios.
User Experience Assessment of Smart Wheelchairs [34]	User experience (UX) assessment of smart wheelchairs with real users. Insights into user satisfaction and frustration points. Limited focus on UX evaluation for elderly users.	Research gap in conducting comprehensive UX assessments, especially for elderly users, and using the feedback to improve smart wheelchair designs.

Control options, including voice commands, manual control, Bluetooth control, and gesture control, were chosen to accommodate a diverse range of users with varying disabilities. The inclusion of a robotic arm, positioned with user mobility in mind, was a direct response to the desire for greater user independence and interaction. Location tracking and health monitoring functionalities were implemented in response to user feedback, emphasizing the importance of safety and well-being. Throughout the development process, real-world user testing involving individuals with disabilities ensured that the wheelchair's usability and performance met user expectations, with iterative improvements made in response to their suggestions. The design aimed to create a harmonious and intuitive interface, addressing the unique needs and challenges of individuals with disabilities, while hardware and software customization options catered to individual requirements. In essence, the "AssistEase" smart wheelchair was forged with user feedback at its core, ensuring that it is not only technologically advanced but also genuinely inclusive and responsive to the diverse needs of its users.

2) Mobile Application to Control the Wheelchair Robot: There hasn't been enough research that specifically looks at how this technology can work together with mobile apps. [36], [37], [38], [39], [40], [41], [42]. This is an important topic to study because mobile apps are a big part of our lives today, and when we combine smart wheelchair technology with mobile apps, it can give users more ways to control and keep an eye on their wheelchairs.

The Table II provides a summary of the research gap of wheelchair controller mobile applications. There is a requirement for smart wheelchair apps that cater to users with diverse disabilities. Currently, most of these apps are designed for specific disability types, highlighting the need for adaptable solutions.

TABLE II. SUMMARY OF RESEARCH GAP OF WHEELCHAIR MOBILE APPLICATION

Gap	Description
Integration with mobile applications	Lack of research on the integration of smart wheelchair technology with mobile applications
Accessibility	There's not enough research focusing on creating smart wheelchair apps that can adjust to the requirements of various users.
Natural language processing	There's a shortage of research when it comes to building NLP models for smart wheelchair apps.
Personalized navigation	There's not enough research focused on implementing personalized navigation in smart wheelchair apps.

Additionally, there's a research gap regarding the incorporation of natural language processing (NLP) in smart wheelchair apps. [42], [43], [46], [47], [48], [49], [50], [51], [52], [53]. While some research has explored speech recognition [77], [78], [79], [80], there is a lack of research on NLP models. These modules can identify dialects accurately with an understanding of different languages. There is a need for research into gamification and personalized navigation with smart wheelchair apps. Many existing apps focus mainly on navigation, but there is a demand for apps that offer users a more engaging and personalized experience.

3) Communication Device with Home Management System: Despite notable advancements in smart wheelchair technology, as evidenced by previous studies [87], [88], [89], [90], [91], [96], there remains an urgent need for the integration of language translation and smart home capabilities. This need is particularly crucial for individuals who are blind, deaf, or mute, as it can significantly improve their daily routines. To address these market gaps, our research is dedicated to the development of a multifaceted device that seamlessly combines braille, sign language, and voice translation as integral components of a smart wheelchair. Our core focus is on affordability, aiming to effectively bridge the current market gap.

Furthermore, contemporary smart home systems often rely predominantly on voice commands for control, which may not always be practical or preferred in various scenarios. As a result, there is a growing demand for comprehensive solutions that not only enhance functionality but also improve accessibility. Our research direction is geared towards empowering individuals with visual or auditory impairments by enabling them to connect with smart home systems through the creation of an innovative device. This device allows the control of smart home functions using braille inputs, thereby ensuring a more inclusive and connected living environment.

Not only would this make controlling the smart home more intuitive for blind individuals and people with speech impairments, but it would make reaping the benefits of these advanced technologies easier for them as well.

This research initiative is summarized in Table III, highlighting the significance of our approach in addressing the pressing need for enhanced accessibility and functionality in smart wheelchair technology and smart home integration for individuals with disabilities.

TABLE III. SUMMARY OF RESEARCH GAP OF COMMUNICATION DEVICE

Gap	Description
Voice recognition	Existing solutions like BrailleEasy cannot capture voice inputs spoken by the occupant
Seamless integration with a mobile app	Both Vero and BrailleEasy solutions lack the integration with a mobile application
Inbuilt to a smart wheelchair	None of the existing solutions on the market come seamlessly built into a smart wheelchair
Braille-to-Smart home integration	The integration with a smart home technology is lacking in existing solutions

4) Mobile Application in Synchronization with the Communication Device: In the realm of deep learning [54] [55] [97] [102], despite a substantial body of research, there is a noticeable research gap in the development of a dedicated smartphone application seamlessly integrating common object detection mechanisms with complementary features. Previous studies have diligently explored various aspects of object detection techniques, including feature extraction and classification algorithms, as indicated by references. However, there remains a distinct scarcity of research dedicated to the specific integration of these techniques into a real-time smartphone application to ensure a user-friendly experience for everyday object recognition.

Moreover, smart wheelchair applications must be designed to address a wide array of challenges faced by individuals with disabilities. A pivotal challenge involves communication, specifically in the context of understanding sign language. The utilization of advanced deep learning techniques, such as convolutional neural networks (CNN) [27], [28], [29], [58], [59], stands out for its proficiency in identifying and recognizing hand motions, facilitating seamless sign language communication [61], [62], [63], [64], [65]. This capability is particularly invaluable in situations where individuals may struggle to express themselves, ensuring that their voices are heard and preventing potential adverse consequences. To deepen our research gap analysis, it is imperative to conduct comprehensive assessments of the application's usability and user experience. This should be undertaken with a keen awareness of the unique requirements of sign language users. Usability, which pertains to the application's accessibility and ease of engagement, must be a primary focus. Simultaneously, the user experience, in terms of satisfaction and enjoyment derived from using the application, must be taken into account. Prioritizing these aspects in our research is not merely important; it is paramount. This emphasis drives the development of technologies that are not only user-friendly but profoundly inclusive, effectively meeting the diverse needs of individuals with disabilities. This approach ensures a robust and holistic research gap analysis, highlighting the significance of the proposed solution in bridging this gap, which is summarized in Table IV.

Considering the severity of these issues faced by wheelchair users, it is imperative to offer solutions that help them become tech-savvy and meet their essential requirements for app operation. This entails creating applications that are accessible to a wide range of users with diverse needs. Furthermore, the inclusion of additional features that enhance user-friendliness can substantially enhance the overall user experience and mitigate the difficulties experienced by wheelchair users, ultimately contributing to their well-being. Technology serves as a valuable tool in addressing the specific challenges confronted by wheelchair users, making it an essential asset in improving their quality of life.

IV. METHODOLOGY

The development of a smart wheelchair robot and a mobile application designed for health monitoring and communication among differently-abled individuals brings forth a spectrum of ethical concerns and privacy issues that necessitate rigorous consideration. Privacy of sensitive health data, encompassing vital signs and medical histories, is paramount, demanding robust encryption, secure storage, and access control. Informed consent from users, particularly those with disabilities, is a fundamental ethical requirement, ensuring that individuals comprehensively understand data collection, its purpose, and who can access it. Clear policies surrounding data ownership, giving users control over their health data, and data security in communication channels are vital ethical facets. Preserving user autonomy and decision-making capacity is equally critical, with technology designed to enhance independence without undermining choice. Ethical responsibilities also extend to transparency, inclusivity, and accessibility. In addition, considerations for ethical data sharing and adherence to research ethics are crucial, emphasizing user consent and compliance with privacy regulations. Striking a balance between the technology's benefits and ethical and privacy considerations, safeguarding user rights and personal data, is the ethical cornerstone of such innovations.

TABLE IV. SUMMARY OF RESEARCH GAP OF COMMUNICATION MOBILE APPLICATION

Gap	Description
Tailored smartphone-wheelchair integration	Existing systems do not address the specific needs of individuals using wheelchairs, and there is a lack of technology that caters to the diverse requirements of different generations of users
Inclusive technology design	The ease of technology for individuals with disabilities a concern, and there is a need to create inclusive technologies that accommodate a wide range of features to meet the needs of wheelchair users effectively
Comprehensive solutions	There is currently no proposed system that handles all the identified problems together as one, integrating features such as hand gesture detection, scheduling remainders
Sign language recognition smartphone app	There is a significant research gap in the development of a tailored smartphone app that effectively incorporates real-time sign language recognition while providing additional user-friendly features
Usability and user experience	There is a lack of focus on analyzing the app's usability and user experience, especially concerning the unique needs of people. This includes how straightforward the app is to access and engage with, as well as how satisfied and entertained users are with the app

This system, shown in Fig. 2, uses different tools to control wheelchairs. These include a microphone, camera, gesture control (which senses hand movements), braille keyboard, Bluetooth (for wireless connection), joystick, ultrasonic sensor (which senses distance), pressure sensor (which senses touch), temperature sensor (which senses temperature), and a GPS module (which tracks the location). All of these components are connected to the wheelchair. The camera and microphone are especially important for talking and listening. They help to communicate with the wheelchair user. Both the communication part and the wheelchair part of the system have their batteries that can be charged. All of this connects to a mobile app. So, you can control and access everything from your mobile phone. It is like having a remote control for your smart wheelchair.

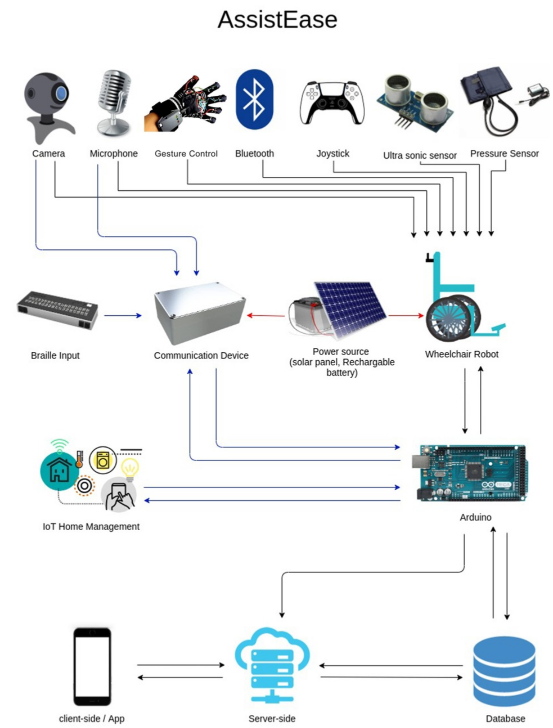


Fig. 2. Methodology Diagram of the System

A. Wheelchair Robot

The process of planning and creating the smart wheelchair was done with great care, aiming to include advanced features such as various control options, a robotic arm, location tracking, and health monitoring. Fig. 2 shows all the components of the wheelchair. During the design phase, we established a modular framework to smoothly integrate these different parts. For development, we utilized a combination of standard and custom hardware, such as the Arduino UNO, which is based on the ATmega328P. It has a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. Also used are the ESP8266 WiFi Module, which is a TCP/IP protocol stack that can give any microcontroller access to a WiFi network, and the Bluetooth Module, which has a sensitivity of -84 dBm at 0.1% BER.

Used L298 module to control the speed and spinning direction of direct current motors, sensors such as MAX30102, which has a range of -40^{o}C to $+85^{o}$C with an accuracy of 1^{o}C to read body temperature, and MAX30105, a highly sensitive sensor to read pressure.

The software aspect involved real-time systems and control interfaces for each of the four control modes: voice commands, manual control, Bluetooth control, and gesture control. We also added a robotic arm to improve user independence and interaction, making sure it didn't interfere with mobility. For location tracking, we relied on GPS technology, while the health system gathered important data about vital signs and posture. This data was continuously analyzed in real time shown in Fig. 3.

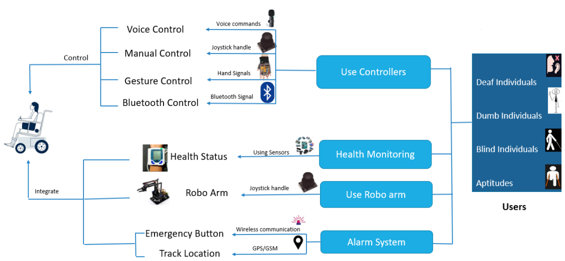


Fig. 3. Methodology Diagram of the Smart Wheelchair System

To ensure the wheelchair's performance and ease of use, we conducted thorough evaluations. The flowchart shown in Fig. 4 illustrates how all the wheelchair components are controlled. The goal was to ensure that the different functionalities could work harmoniously without compromising the wheelchair's stability or usability. The development utilized a combination of off-the-shelf and custom hardware components. These included microcontrollers for processing, motors, and actuators for movement and manipulation, sensors for feedback, and communication modules for data exchange.

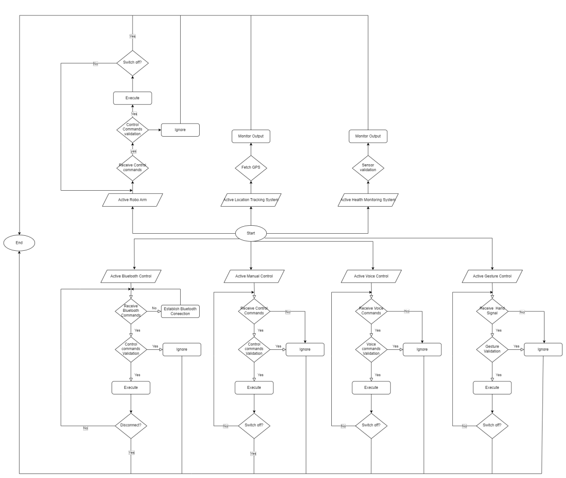


Fig. 4. Wheelchair Flowchart

The software stack included real-time operating systems, control algorithms, and user interfaces tailored for each control mode. Safety features in smart wheelchairs play a pivotal role in ensuring the well-being of users. Obstacle detection and avoidance, powered by ultrasonic sensors, significantly reduce the risk of collisions and enhance mobility in varied environments. The emergency alert system, with remote notifications, provides an immediate response in critical situations, offering peace of mind to users and their caregivers. The manual brake gives users control over their movements, fostering empowerment and independence. Collectively, these features create a comprehensive safety net, mitigating risks and enhancing the overall safety of wheelchair users, allowing them to navigate their surroundings with confidence and autonomy.

B. Mobile Application to Control the Wheelchair Robot

The flowchart shown in Fig. 5 illustrates how the smart wheelchair app works step by step. It all begins when the user opens the app on their device. First, we check the color theme of users; device to make sure the app looks good and matches users' devices' colors. Next, the app opens, showing the right colors. If the user has not used the app before, ask the user to create an account. This is like signing up and creating a username and password to keep information safe. If the user already has an account, they can simply log in by typing in their username and password.

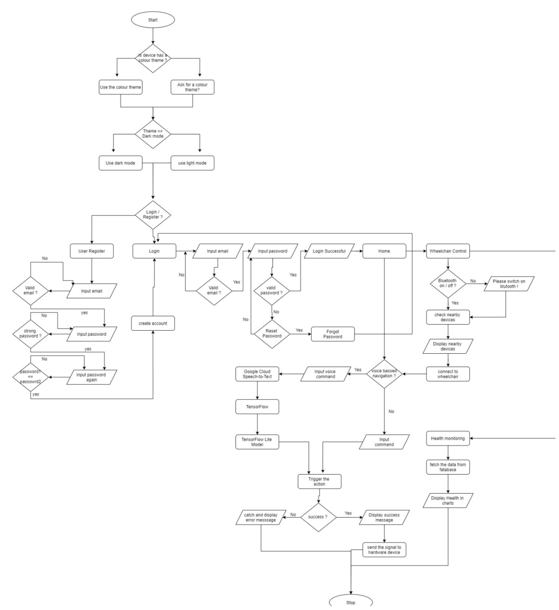


Fig. 5. Wheelchair controller mobile application Flowchart

This is to make sure only the right people can use the app. Once the user has logged in successfully, they will see the main page of the app, where they can do all the important stuff. But before the user can do anything, they need to connect the app to the smart wheelchair. If the user forgets to do this, the app will remind them. After the app and the wheelchair are connected, the user can start controlling the wheelchair using the app. The user can use buttons and gestures to make the wheelchair move however they want. Or, if the user prefers, the user can control the wheelchair by talking to it. Just choose the language you want to use: Sinhalese, English, or Tamil.

The app also has some other cool features. Users can see where they are on a map and keep an eye on their health, like blood pressure.

These features make sure the user is safe and can get the most out of smart wheelchairs. This flowchart guides you through the app so that you can easily control smart wheelchairs and use all its great features.

C. Communication Device with Home Management System

The input recognition component consists of two main components aimed at developing the 'AssistEase' system for improved accessibility and convenience for individuals with disabilities shown in Fig. 6. The first component involves creating a language recognition and translation device capable of accurately recognizing hand-sign inputs and braille inputs from the users. This component is crucial for the success of the entire project. It needs to identify two main languages: braille, used by the blind, and hand signs, the primary form of communication for individuals with speech impairments. To recognize hand signs, an advanced vision-based sign language recognition system, integrated with neural networks (CNN), will be implemented. The device will be housed unobtrusively within the smart wheelchair, utilizing 3D printing techniques for efficient design.

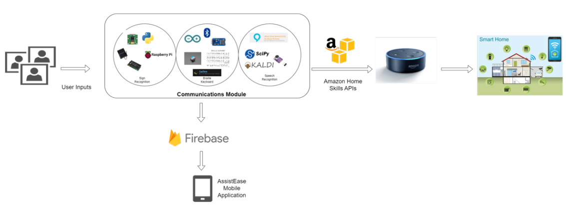


Fig. 6. Communications Device methodology

The project will use a Raspberry Pi Camera Module V2 and various sensor modules to recognize hand gestures. It will be powered by solar energy to reduce the need for batteries. The second part of the project involves creating a smart home command system for people who are deaf and have difficulty speaking, using the Braille language. This system will understand braille commands from these individuals and communicate them to the smart home hub for execution. We prioritize accuracy, and the system will solely rely on braille language commands to control the smart home. Recognizing user inputs will use the same technology as language recognition and translation, using advanced tools like the Microsoft Cognitive Services API and Amazon Alexa Smart Home Skill API to accurately filter and relay commands. Our goal is to ensure that smart home technology is accessible to everyone, regardless of their physical or mental abilities, to improve their quality of life.

The proposed communications mobile application leverages machine learning (ML) techniques, specifically deep learning (DL), to achieve real-time image recognition and classification into respective labels. This ML-powered image classification capability will be integrated into the application to facilitate gesture detection, enabling users to control various features effectively. Additionally, the system will employ the ML model's outputs to compile and send emergency messages to the appropriate parties when needed. Notably, the application offers a range of useful features, including schedule reminders, magnifiers, screen readers, and the ability to control Internet of Things (IoT) devices from a centralized platform shown in Fig. 7. By harnessing the power of ML and DL, the system aims to enhance user experience, accessibility, and overall functionality, catering to the diverse needs of smart wheelchair users and improving their daily lives.

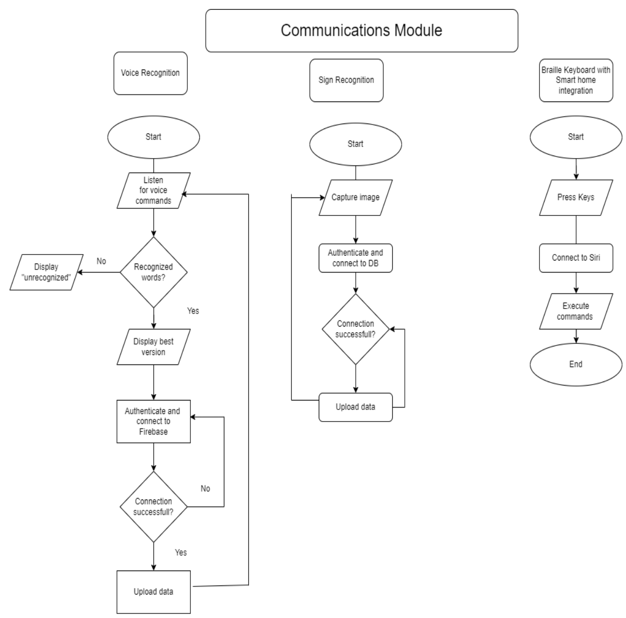


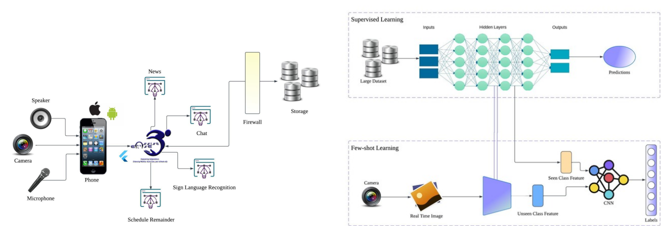
Fig. 7. Flowchart of the Communications Device

D. Mobile Application in Synchronization with the Communication Device

The proposed mobile application in this module will be built using the Model-View-Controller (MVC) software design pattern, which provides a disciplined way of organizing various components of the application. This consists of three layers: model, view, and controller. The model layer will be in charge of data storage and management, ensuring that only valid and accurate information is stored. The view layer, which is the user-facing interface, will be designed and implemented with a strong emphasis on user experience (UX) and user interface (UI) design principles.

The success of the system heavily relies on the effectiveness of this layer in providing a user-friendly and visually appealing interface. The Controller layer serves as a middleman between the View and Model layers, handling user inputs, communicating with the Model layer, and retrieving responses to fulfill user requests. This separation of concerns enables easier debugging and maintenance of the system.

Fig. 8 shows the high-level design of the mobile app with sign language recognition, including the key features and how recognition works. We intend to use Flutter as the programming language and Firebase as the database for the development of applications. Flutter and Firebase are Google-compliant technologies that provide seamless integration and efficient connectivity. Flutter provides a diverse set of libraries and resources, resulting in the flexibility and convenience of implementing various features. Its cross-platform capabilities enable easier deployment on different platforms, enhancing flexibility and accessibility. Additionally, Flutter's hot-reload feature allows real-time compilation and instant reflection of changes during development and testing, facilitating a smoother development process.



(a) Enhanced System Diagram (b) Working Principle

Fig. 8. Mobile Application Synchronization with Communication Device

In our research, it's crucial to create an app that's easy for users to navigate. The technologies we've chosen and the design approach we're using support this goal. Flutter is known for its versatility, flexibility, and ability to provide real-time updates, all of which help us to make an app that meets user needs. By using the MVC pattern and making the most of Flutter and Firebase, our aim is to build a strong and user-friendly smartphone app. This app will have features such as recognizing sign language and other tools to enhance communication and accessibility.

A significant hurdle that individuals with disabilities often face is the barrier to effective communication. For those born mute or reliant on sign language, expressing themselves can be challenging, as not everyone understands sign language. To overcome this obstacle, we have harnessed the power of sign language recognition technologies. This cutting-edge technology empowers machines to interpret sign language, facilitating interaction between those who are proficient in sign language and those who are not. The introduction of sign language recognition is paramount and leverages foundational concepts in machine learning (ML), deep learning (DL), and artificial intelligence (AI) to train machines to emulate human behavior. These technologies are instrumental in enabling machines to recognize intricate patterns and interpret gestures, thereby laying the foundation for effective sign language recognition. The sign language recognition process, shown in Fig. 9, involves acquiring, pre-processing, extracting features from, classifying, and translating sign language data as per users' requirements.

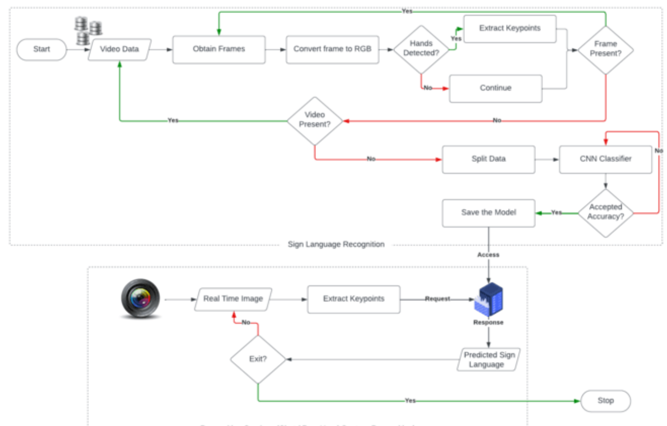


Fig. 9. Flowchart: Sign Language Recognition

We harnessed the power of YoloV8, a state-of-the-art object detection model that has achieved impressive results in previous works [56], [57], [99]. Our training process was facilitated by a meticulously labeled dataset, which was sourced from Roboflow and Kaggle, as indicated in Fig. 10. This comprehensive dataset integration, combined with its seamless integration into a mobile app via Flutter Vision, paves the way for real-time sign language recognition. Our journey to develop this gesture detection application was not without its challenges. Recognizing sign language gestures in real-time presents hurdles in diverse environmental settings. Variability in lighting conditions, background clutter, and occlusions affected recognition accuracy; despite our best efforts, we managed to get an accuracy of around 90%. The system encountered difficulties in capturing certain intricate signs and recognizing variations in hand motions. Our approach not only offers a deeper understanding of the proposed system but also promises a more inclusive and accessible communication experience for individuals reliant on sign language. The choice of Python, a versatile programming language teeming with a vast array of libraries, is particularly well-suited for this domain, ensuring the versatility and robustness needed for success in this field.

Python is a great choice for creating sign language recognition algorithms, especially in the field of data science, where it has a robust ecosystem. While we cannot solve all the

Fig. 10. Flowchart: Sign Language Recognition

challenges faced by people with disabilities, we focus on what we can improve through technology. Our main goal is to use technology to support individuals with disabilities, addressing their unique difficulties and improving their quality of life. By adding features such as sign language recognition to applications, we take significant steps toward the goal. Our vision is to build a society that offers equal opportunities and fair access to resources for everyone. To create a user-friendly and feature-rich application, we rely on technologies such as Flutter, Firebase, and the MVC design pattern. MVC makes it easier to create, test, and maintain the application, while Flutter ensures that it works on different devices, reaching a broader audience. Firebase adds real-time updates, enhancing the overall user experience. Combining these technologies gives us a solid foundation for developing a customized application for smart wheelchair users that is easy to use and packed with useful features. Ultimately, this combination of technologies can make a sign language application successful by creating a user-friendly, feature-rich, and accessible tool for a wide range of users.

To achieve the objectives of designing and integrating the AssistEase smart robot wheelchair with the development of a feature-rich communications device and a mobile application, a methodological approach canbes used. Begin with a comprehensive needs assessment and engaged users and healthcare professionals to identify specific requirements. Designed the hardware and software components for the smart wheelchair. Safety mechanisms and connectivity to communication devices and mobile apps are vital. We conducted rigorous testing with users for iterative improvements. For the communications device, understand communication needs, develop hardware and software, and ensure integration with the wheelchair. In the mobile app, prioritize accessibility, user-friendly design, and functionality, with connectivity to both the wheelchair and communication device. Finally, create APIs for seamless integration, focus on security, conduct usability testing, and provide user training. Involving individuals with disabilities at every step is crucial to tailoring these solutions effectively while adhering to relevant regulations.

In the development of the AssistEase smart wheelchair system, aimed at improving mobility and communication for people with disabilities, interdisciplinary collaboration plays an essential role. A professor who is interested in semantic web robotic middleware, IoT, and algorithms related to operating systems and computer systems and network engineering undergraduates design the system's hardware components, while a lecturer who is interested in computational linguistics, natural language processing, machine learning, artificial intelligence, and image processing and software engineering undergraduates develop sign language recognition algorithms and voice recognition with natural language processing in English, Sinhalese, and Tamil languages. Additionally, there is a physIoTherapist providing information on user needs and a wheelchair user advocate representing end users.

Smart wheelchair systems, such as the AssistEase smart wheelchair and its accompanying mobile application, hold great promise in significantly improving the quality of life of people with disabilities. These systems offer enhanced mobility, real-time health monitoring, effective communication tools, and improved safety, all of which enable users to lead more independent and fulfilling lives. By seamlessly navigating various environments, avoiding obstacles, and facilitating access to a wide range of places, these smart wheelchairs promote greater mobility and inclusion. The integrated health monitoring features ensure that users' well-being is continuously monitored, allowing for early detection of health issues and prompt medical intervention. Moreover, the sign language and voice recognition capabilities enable individuals with speech and hearing impairments to communicate with their caregivers, family, and friends, fostering stronger connections and support networks. In settings such as hospitals, schools, workplaces, and daily living situations, these systems break down barriers, making education, employment, and social participation more accessible. With the potential to customize settings and controls and promote inclusivity among various users, smart wheelchair systems represent a leap toward a more inclusive, convenient, and independent way of life for people with disabilities.

V. Testing

The testing and evaluation plan for the AssistEase smart wheelchair system aims to make sure it works well and is useful for people with disabilities. We ask people with disabilities to try it out and tell us what they think. We test how easy it is to use, how well it works, and how safe it is, especially when it comes to avoiding obstacles. We also check how accurately it monitors health information, which is important for users' well-being. We gather feedback and ask users if they are happy with the system. Throughout this process, we make sure we follow rules about privacy and ethics to protect sensitive health information. We collaborate with experts from different fields to make the system better. The results of these tests help us improve the system so that it truly helps people with disabilities and improves their lives.

A. Wheelchair Robot

1) Control Methods Testing: In order to assess the functionality and effectiveness of the implemented control methods, a series of controlled experiments were conducted.

According to the Table V, the four primary control methods, namely Bluetooth, manual, gesture, and voice control, were individually tested under various scenarios to evaluate their performance and reliability.

TABLE V. CONTROL METHOD TESTING

Test Type	Success Rate	Observation and Comment
Bluetooth Control	90	High responsiveness; occasional connectivity issues.
Manual Control	95	Proficient control across different flooring types.
Gesture Control	85	Variable success due to gesture recognition accuracy.
Voice Control	80	Generally successful, occasional misinterpretations.

- For Bluetooth control testing, participants were asked to pair their smartphones with the Bluetooth module of the wheelchair robot. They were then instructed to navigate the wheelchair through a predefined obstacle course consisting of tight turns, straight paths, and varying surface types (mat floor, wood floor, and tiles). The participants' ability to accurately control the wheelchair's movements and navigate around obstacles was evaluated. The results indicated that the Bluetooth control exhibited a high degree of responsiveness and accuracy, and participants successfully maneuvered the wheelchair throughout the course in 90 of the cases. Challenges in maintaining consistent connectivity were noted in areas with high wireless interference.
- Manual control testing involved participants physically operating the wheelchair using a joystick-based control interface. Similar obstacle course scenarios were employed to assess the wheelchair's maneuverability, stability, and ease of control across different flooring surfaces. Participants demonstrated proficient control of the wheelchair on many types of flooring, achieving a success rate of 95 in obstacle navigation. Manual control showcased reliability and adaptability, allowing users to effectively navigate through confined spaces and around obstacles.
- Gesture control testing required participants to perform predefined hand gestures to command the wheelchair's movements. The gestures included forward, backward, left, and right motions. The participant's execution of gestures and the corresponding wheelchair responses were evaluated. Gesture control exhibited a success rate of approximately 85, with some variability attributed to individual gesture recognition accuracy. While gesture control offered a hands-free option for users with limited mobility, improvements in gesture recognition algorithms could enhance its overall effectiveness.
- Voice control testing involved participants giving voice commands to control the wheelchair's movements. A set of common voice commands were defined, such as "move forward," "turn left," and "stop." Participants' ability to accurately convey commands and the robot's response time were assessed. Voice control demonstrated a success rate of 80, with occasional misinterpretations of voice commands due to ambient noise or accents. While offering a convenient and intuitive control method, refinements in speech recognition algorithms could lead to improved accuracy and user satisfaction.

2) Flooring Compatibility Testing: To evaluate the performance of the wheelchair robot on different flooring surfaces, a comprehensive flooring compatibility test was conducted. The objective was to assess the maneuverability, stability, and overall control of the robot on various types of floors, including a mat floor, a wood floor, and tiles. The Table VI shows the test type, success rate, and observation of the testing.

TABLE VI. RESULTS OF FLOORING COMPATIBILITY TESTING

Test Type	Success Rate	Observation and Comment
Mat Floor Testing	100	Consistent control and stability on carpeted surface.
Wood Floor Testing	95	Effective traction and control, minor deviations.
Tile Floor Testing	90	Adaptability to tile textures, minor deviations from the path.

- Mat floor testing involved navigating the wheelchair robot through a designated course on a carpeted surface. The course included sharp turns, straight paths, and simulated obstacles. The performance of the robot in terms of smooth navigation, turning radius, and stability was closely monitored. The results indicated that the wheelchair robot maintained consistent control and stability on the mat floor, successfully navigating the course without any slippage or loss of traction. The soft surface of the mat provided sufficient grip, allowing the robot to perform turns and stops effectively.
- Wood floor testing was conducted to assess the robot's behavior on a harder and smoother surface. Similar to the mat floor test, the robot was tasked with navigating through a predefined course that included both tight turns and straight paths. The aim was to evaluate how the robot's traction and control were affected by the change in surface. The robot also exhibited commendable performance on the

wood floor. Although the smoother surface posed a slight challenge in maintaining traction during sharp turns, the wheelchair's integrated control mechanisms compensated effectively, resulting in a success rate comparable to that of the mat-floor test.

- Tile testing focused on evaluating the robot's performance on a surface with varying levels of friction. The robot was subjected to a course consisting of different tile textures, simulating potential real-world scenarios. The objective was to determine the robot's adaptability to changing surface conditions. The results highlighted the wheelchair robot's ability to navigate the tiles successfully, albeit with some variations in control and stability. The robot exhibited slightly reduced traction on smoother tiles, resulting in minor deviations from the intended path during sharp turns. However, it effectively compensated for this by adjusting its movements accordingly.

The Table VII shows results of the wheel chair's other components.

TABLE VII. RESULTS OF WHEELCHAIR'S OTHER COMPONENTS TESTING

Test Type	Success Rate	Observation and Comment
Accuracy Assessment of Location Tracking System	95	Accurate position tracking compared to ground truth.
Body Temperature of Health Monitoring System	90	Data within normal range; non-intrusive sensors.
Body Pressure of Health Monitoring System	90	Data within normal range; non-intrusive sensors.
Control of Robot Arm	89	Effective control of arm movements via smartphone..

- The location tracking system implemented in the wheelchair robot was subjected to rigorous testing to evaluate its accuracy, reliability, and overall effectiveness in providing real-time position information for navigation and control purposes.To assess the location tracking system's performance, a controlled indoor environment was set up with predefined way points and paths. The wheelchair robot was tasked with navigating through this environment while the location tracking system continuously recorded and updated the robot's position coordinates. The accuracy of the location tracking system was evaluated by comparing the recorded position coordinates with ground truth measurements obtained through a high-precision external tracking system. The discrepancies between the system's reported positions and the ground truth were analyzed to quantify the system's accuracy.
- The health monitoring system was capable of collecting various health metrics, including blood pressure and body temperature, through non-intrusive sensors embedded within the wheelchair. Data was continuously recorded and transmitted to a central database for further analysis. The collected health data were analyzed to provide insights into users' physiological responses during wheelchair operation. The system's ability to detect and respond to changes in health metrics was evaluated, with a focus on identifying potential signs of discomfort or stress. Body temperature measurements showed consistent values within a normal range, confirming the non-intrusive nature of the sensors and the absence of temperature-related discomfort during operation.
- The testing scenarios included picking up objects of varying shapes and sizes placed at different distances from the robot arm. Participants were asked to perform tasks such as grasping, lifting, and releasing objects. The results of the Bluetooth control testing demonstrated that participants could effectively control the robot arm's movements with the smartphone application. The success rate for picking up objects was approximately 85%, with challenges observed in precise object positioning and grasp consistency. Connectivity and responsiveness of the Bluetooth control were generally satisfactory.

B. Mobile Application to Control the Wheelchair Robot

Before getting into the specific test cases, it's important to highlight the thorough testing process that underpins the functionality and dependability of the smart wheelchair application. A set of correct tests, consider both functional and non-functional aspects, has been thoughtfully devised and executed to validate different facets of the application's performance. These tests span various critical areas, such as Bluetooth connectivity, remote control, voice-based navigation, location display, health monitoring, multilingual support, personalized navigation, animation integration, and the toggling between dark mode and light mode. Each test case has been exactly structured to assess distinct functionalities and features, ensuring the application functions smoothly and caters to the diverse needs of users. In the sections that follow, we will provide a comprehensive overview of these test cases shows in the Table VIII, IX, X, XI, and XII including detailed scenarios, input data, procedures, expected outcomes, and the actual results obtained during testing. This comprehensive approach serves as a robust foundation for evaluating the application's performance and reliability.

1) Bluetooth Control: This Table VIII outlines a specific test, identified by the Test Case ID "A001," which assesses the Bluetooth connection functionality within the context of a smart wheelchair application. The purpose of this test is to ensure that the application can successfully establish a Bluetooth connection with the smart wheelchair device. This valuable record of the test demonstrates that the application performed as expected, successfully establishing a Bluetooth connection, a crucial component of its functionality, and is essential for evaluating the application's performance and ensuring its reliability in real-world usage scenarios.

TABLE VIII. Testing and Implementation - Bluetooth connection

Test Case ID	A001
Test Scenario:	Bluetooth Connection
Test Input Data:	Ensure Bluetooth is turned on
Test Procedure:	Open the app. Ensure Bluetooth is turned on. Click on "Connect to Device."
Expected Outcome:	App establishes a Bluetooth connection with the smart wheelchair device.
Actual Outcome:	Established a Bluetooth connection with the smart wheelchair device.
Test Results:	Pass

2) Voice Based Navigation In Different Languages: Table IX presents the results of Test Case ID "A002," which focuses on evaluating the voice-based navigation feature within the smart wheelchair application. The test scenario involved using spoken voice commands in three different languages: Sinhalese, Tamil, and English. The procedure included opening the application, connecting to the smart wheelchair device, and issuing voice commands in these languages to control the wheelchair. The expected outcome was that the wheelchair would respond appropriately to voice commands in the selected language.

The actual outcome confirmed that the wheelchair indeed responded to voice commands as expected, resulting in a "pass" status for this test. This test ensures that the voice-based navigation feature functions effectively, accommodating various languages and facilitating user-friendly control of the wheelchair. Many researchers have done much research work related to robot navigation with different algorithms [69], [70], [71], [72].

TABLE IX. Testing and Implementation - Voice Based Navigation

Test Case ID	A002
Test Scenario:	Voice-Based Navigation
Test Input Data:	Spoken voice commands in different languages (Sinhalese, Tamil, English)
Test Procedure:	Open the app. Connect to the smart wheelchair device. Use voice commands in Sinhalese, Tamil, and English to control the wheelchair.
Expected Outcome:	Wheelchair responds to voice commands in the selected language.
Actual Outcome:	Wheelchair responded to voice commands in the selected language.
Test Results:	Pass

3) Location Display: Table X, summarizes the results of Test Case ID "A003," which focuses on assessing the location display functionality within the smart wheelchair application. The test scenario involved verifying the accuracy of location information displayed in the app. To conduct the test, the application was opened, and a connection was established with the smart wheelchair device. Subsequently, the location display feature on the app was examined.

The expected outcome was that the app would accurately display the user's precise location using GPS data. The actual outcome confirmed that the application indeed displayed the user's location accurately, resulting in a "pass" status for this test. This test underscores the application's capability to effectively utilize GPS data to provide users with an accurate and reliable representation of their location, enhancing the wheelchair's navigational features.

TABLE X. Testing and Implementation - Location Display

Test Case ID	A003
Test Scenario:	Location Display
Test Input Data:	Access to GPS data
Test Procedure:	Open the app. Connect to the smart wheelchair device and check location display on the app.
Expected Outcome:	App displays the user's precise location using GPS data.
Actual Outcome:	App displayed the user's precise location using GPS data.
Test Results:	Pass

4) Health Monitoring: Table XI outlines the results of Test Case ID "A004," which focuses on evaluating the health monitoring feature within the smart wheelchair application. The test scenario involves assessing the application's ability to access and display vital health data, specifically blood pressure and heart rate (bpm). To execute the test, the application is opened and connected to the smart wheelchair device. Subsequently, the health monitoring section of the app is examined. The expected outcome is that the application accurately and in real-time displays the user's blood pressure and bpm data. The actual outcome confirms that the app indeed achieved this, resulting in a "pass" status for the test. This test demonstrates the application's capability to provide users with essential health information while using the smart wheelchair, enhancing their overall well-being and safety.

5) Multilingual Support: Table XII provides an overview of results for Test Case ID "A005," which focuses on evaluating the Multilingual Support feature within the smart wheelchair application. The test scenario involves testing the application's capability to understand and respond to voice commands in multiple languages, including Sinhalese, Tamil, and English. The test procedure includes opening the application, establishing a connection with the smart wheelchair device, and issuing voice commands in the specified languages. The expected outcome is that the application accurately comprehends and responds to voice commands in the chosen language. The actual outcome affirms that the application indeed met this expectation, resulting in a "pass" status for the test. This test demonstrates the application's ability to accommodate a diverse user base by providing effective multilingual support, enhancing its usability and accessibility for a broader audience.

TABLE XI. TESTING AND IMPLEMENTATION - HEALTH MONITORING

Test Case ID	A004
Test Scenario:	Health Monitoring
Test Input Data:	Access to health data (blood pressure and bpm)
Test Procedure:	Open the app. Connect to the smart wheelchair device. Check the health monitoring section on the app.
Expected Outcome:	App displays the user's blood pressure and bpm data accurately and real-time.
Actual Outcome:	App displayed the user's blood pressure and bpm data accurately and real-time.
Test Results:	Pass

TABLE XII. TESTING AND IMPLEMENTATION - MULTILINGUAL SUPPORT

Test Case ID	A005
Test Scenario:	Multilingual Support
Test Input Data:	Voice commands in different languages
Test Procedure:	Open the app. Connect to the smart wheelchair device. Use voice commands in Sinhalese, Tamil, and English.
Expected Outcome:	App accurately understands and responds to voice commands in the selected language.
Actual Outcome:	App accurately understated and responds to voice commands in the selected language.
Test Results:	Pass

The comprehensive testing and implementation of the mobile application for the smart wheelchair have yielded promising results, as summarized in Table XIII. Each feature underwent rigorous evaluation, and the recorded accuracy percentages demonstrate the application's overall effectiveness and reliability.

The Bluetooth Connection feature exhibited a commendable accuracy rate of 95%, indicating its consistent ability to establish Bluetooth connections with the smart wheelchair device. This ensures seamless communication between the application and the hardware.

Voice-Based Navigation, with an accuracy rate of 94%, showcases the application's proficiency in understanding and responding to voice commands, enhancing the user's navigational experience.

The Location Display feature impressively achieved an accuracy rate of 96%, underscoring its capability to provide users with precise and real-time location information using GPS data.

Health Monitoring, responsible for tracking blood pressure and bpm data, maintained an accuracy rate of 95%, reinforcing its role in enhancing user safety and well-being.

Multilingual Support, with an accuracy rate of 92%, demonstrates the application's versatility in accommodating a diverse user base by comprehending and responding to voice commands in different languages.

TABLE XIII. TESTING AND IMPLEMENTATION - TEST ACCURACY OF WHEELCHAIR CONTROLLER MOBILE APPLICATION

Test Case	Accuracy
Bluetooth Connection	95%
Voice-Based Navigation	94%
Location Display	96%
Health Monitoring	95%
Multilingual Support	92%

The mobile application for the smart wheelchair has proven its mettle through thorough testing, offering robust features that not only enhance mobility but also prioritize user health and accessibility. These results shown in Table XIII serve as a testament to the application's reliability, setting the stage for its broader implementation to empower individuals with mobility challenges and diverse linguistic backgrounds. Further refinement and continuous improvement will ensure that this technology continues to serve its users effectively in the future.

C. Communication Device with Home Management System

The Table XIV shows testing and results of the communication device.

TABLE XIV. RESULTS AFTER TESTING THE COMMUNICATION DEVICE

Test Type	Success Rate	Observation and Comment
Voice Recognition Module Testing	80%	Impressive accuracy rate in interpreting user commands, demonstrating proficiency, while variations in ambient noise, speaker accents, and enunciation clarity slightly impacted its performance.
Hand Gesture Recognition Module Testing	85	Accuracy is good but can be affected by lighting conditions, proximity to the sensor, and variations in gesture execution.
Braille Keyboard Testing	90	Displayed high accuracy in registering Braille characters with minimal input latency.

1) Voice Recognition Module Testing: Several tests using sentences of various lengths were carefully used to assess the speech recognition module's effectiveness. The central objective was to gauge its ability to accurately comprehend user commands. Impressively, the module exhibited an 80-percent accuracy rate in correctly interpreting the provided commands.

The Google Speech Recognition API's incorporation greatly aided in this accomplishment, a well-established technology renowned for its proficiency in transcribing spoken language to text. The Google Speech Recognition API, powered by advanced machine learning techniques like deep neural networks, greatly contributed to the voice recognition module's success. It is pertinent to acknowledge that the module's accuracy might be influenced by factors like ambient noise, speaker accents, and enunciation clarity.

2) Hand Gesture Recognition Module Testing: Thorough testing was conducted on the hand gesture recognition module, which utilized the ESP32 microcontroller. This module's accuracy in detecting and interpreting hand gestures was paramount. The testing regimen encompassed a spectrum of controlled gestures performed by distinct individuals. Each gesture corresponded to a specific command, and the module's recognition accuracy was evaluated by comparing executed gestures to recognized commands. Impressively, the hand gesture recognition module demonstrated an 85-percent accuracy rate, signaling its robustness in appropriately identifying and comprehending user gestures.

However, it is imperative to acknowledge that this accuracy can be influenced by factors such as lighting conditions, proximity to the sensor, and variations in gesture execution. Future iterations could explore advanced sensor configurations, machine learning algorithms, or data augmentation techniques to further enhance accuracy. The reliability and accuracy of the ESP32 camera module played a pivotal role in shaping the research's outcomes. The module, encompassing a compact camera sensor, showcased its prowess in real-time visual information capture and processing. This capability was instrumental in realizing the hand gesture recognition component's success. While the module exhibited stability in controlled settings, there exists potential to improve its adaptability to diverse lighting conditions and complex backgrounds. This improvement could further elevate accuracy and reliability.

3) Braille Keyboard: A significant facet of our research involved conceiving a Braille keyboard through ESP32 and Arduino platforms. This innovation empowers visually impaired individuals by providing them with a tool for digital input. The amalgamation of ESP32 and Arduino components resulted in a versatile and accessible Braille keyboard system.

Each switch on the tactile switch matrix of the Braille keyboard corresponded to a Braille dot. Keypress combinations translated into Braille characters, facilitated by the ESP32's role in capturing, processing, and transmitting input to connected devices. Testing substantiated the Braille keyboard's high accuracy in registering Braille characters and minimal input latency. This establishes the potential of the system to enhance digital interaction for individuals with visual impairments. It is crucial to acknowledge that refining the Braille keyboard's design, layout, and functionality can be enriched through user feedback and iterative enhancements, ensuring optimal usability and impact. At present, the Keyboard consists of keys and has compact dimensions that make it possible to be integrated into the armrest of the smart wheelchair.

The testing outcomes unveiled in this research highlight the considerable strides made in the domains of voice recognition, hand gesture recognition, and Braille keyboard development. These achievements bear the potential to reshape human-computer interaction, offering inclusive and innovative ways for individuals to engage with technology. While the results are indeed promising, a deeper exploration and analysis of the implications, challenges, and future directions are essential to comprehend the full scope of these advancements.

4) Voice Recognition and Hand Gesture Recognition Synergy: The integration of voice recognition and hand gesture recognition modules showcases a holistic approach to human-computer interaction. With the inclusion of these technologies, individuals using the AssistEase wheelchair gain the ability to easily communicate with the outside world using their preferred mode of communication with the comfort of having the communication interface directly integrated into the wheelchair itself. The synergy between these modalities could lead to multi-modal interaction, where users seamlessly alternate between voice commands and gestures, enriching user experiences. However, achieving seamless integration is not devoid of challenges. Ensuring synchronization between voice and gesture inputs and addressing scenarios where both modes conflict will be crucial for refining the combined user experience.

5) Google Speech Recognition API and Potential Limitations: While the voice recognition module exhibited an 80% accuracy rate and is able to clearly distinguish voices in general room noise levels in the 30 - 35 DBA range, the reliability of this accuracy under diverse conditions warrants further exploration. The Google Speech Recognition API's dependency on extensive training data might result in challenges when faced with unique or specialized vocabularies. Moreover, addressing issues related to accent and dialect variations remains crucial, especially for global accessibility.

6) Enhancing Hand Gesture Recognition: The hand gesture recognition module, boasting an 85% accuracy rate, marks a notable accomplishment. However, its real-world application could be influenced by factors such as inadequate lighting, cultural variations in gestures, and accommodating a broader range of hand movements. Future research could delve into leveraging advanced computer vision techniques and machine learning algorithms to tackle these challenges, potentially elevating accuracy levels and expanding the repertoire of recognized gestures.

7) Braille Keyboard Accessibility: Creating the Braille keyboard system is a big step in making digital technology more accessible for visually impaired people. The system is very accurate and responds quickly, which means it can help with communication effectively. However, there are some important things to work on. We need to make the interface even easier to use, support more languages, and make sure it works on different devices. It's crucial to involve visually impaired users in this process so that the keyboard system can truly meet their needs and be as helpful as possible.

As we look forward, these advancements set the stage for a myriad of possibilities. Future research could explore the amalgamation of all three modules into a unified system, offering a comprehensive and adaptive approach to interaction. Furthermore, adapting these technologies to accommodate real-world, dynamic scenarios will be essential, necessitating the creation of robust adaptive algorithms and refined hardware configurations. In conclusion, this research not only highlights the achievements in voice recognition, hand gesture recognition, and Braille keyboard technology but also emphasizes the ongoing journey of innovation and refinement. Additionally, the user inputs given by users aren't shared with any third party which guarantees that their privacy is protected to the utmost degree. The path ahead involves addressing challenges, refining accuracy, and deepening accessibility to truly harness the potential of these advancements in real-world settings.

D. Mobile Application Synchronization with the Communication Device

The successful development of the mobile application, featuring sign language recognition and chat service integration, marked a significant milestone in assistive technology. However, ensuring its functionality, usability, and effectiveness required a rigorous testing and implementation process.

- Data Quality Assurance: The first critical phase of testing involved data quality assurance. The dataset obtained from Kaggle, while extensive and diverse, required meticulous examination and validation. Roboflow was employed to label the dataset accurately. This painstaking process ensured the reliability of the training data, which is paramount for the subsequent performance of the sign language recognition model.
- Model Training and Optimization: With a reliable dataset in hand, the YOLOv8 model was trained and optimized to recognize a wide range of sign language gestures. Model training included iterations to fine-tune parameters and enhance accuracy. Continuous monitoring and evaluation were conducted to ensure that the model achieved optimal performance.
- Integration with Flutter Vision: Integration of the trained model into the Flutter Vision framework was a crucial step in the implementation process. Flutter Vision's versatility allowed for the seamless incorporation of computer vision capabilities into the mobile application, enabling real-time sign language recognition directly on the user's mobile device.
- User-Centric Application Development: The development of the mobile application prioritized user-centric design principles. An intuitive and user-friendly interface was meticulously crafted to facilitate easy interaction. The goal was to ensure that individuals with disabilities, including those using wheelchairs, could navigate and utilize the application with ease.
- Usability and Accessibility Testing: Comprehensive usability and accessibility testing were conducted to evaluate the application's effectiveness in real-world scenarios. Individuals with varying degrees of familiarity with technology and sign language were involved in the testing process. User feedback and observations were invaluable in identifying areas for improvement.
- Integration with Chat Services: The seamless integration of sign language recognition with chat services was a complex, but pivotal, aspect of implementation. This integration allowed users to express themselves through sign language within the chat interface, thereby promoting inclusive communication.
- User Training and Support: The implementation phase also encompassed user training and support. Comprehensive user guides and resources were developed to assist individuals in effectively using the application. Training sessions and ongoing support mechanisms were established to address user queries and concerns.

The Data quality assurance, model training, user-centric application development, usability testing, and seamless integration with chat services ensure the application's functionality and user-friendliness. These processes have paved the way for an innovative and inclusive assistive technology tool that has the potential to significantly improve the lives of people with hearing impairments. User feedback has highlighted the application's strengths in improving communication for users. For example, the integration with chat services allows users to express themselves through sign language within the chat interface, similar to messenger platforms with gesture-based messaging. Although the testing and implementation phases have produced a remarkable application with an accuracy closer to 90%, as shown in Fig. 11, but there is always room for future enhancements and refinements. Future research efforts could focus on expanding the sign language recognition vocabulary, fine-tuning gesture detection accuracy, and exploring advanced natural language processing (NLP) techniques to convert sign language into text or speech. These integral processes have paved the way for an innovative and inclusive assistive technology tool with the potential to significantly enhance the lives of individuals with hearing impairments. Future work should investigate specific recommendations and challenges that could be addressed in these areas, providing a solid foundation for ongoing advances in the field.

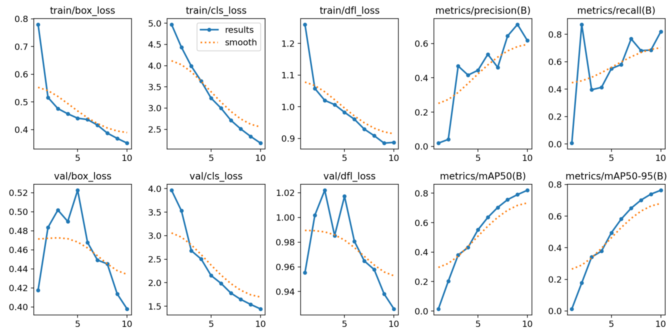


Fig. 11. Result: Sign Language Recognition

VI. Discussion

The discussion of the smart wheel chair and the communication device that help individuals with differently able disabilities is as follows:

A. Discussion of the Wheelchair Robot

Fig. 12 shows the prototype of the AssistEase wheelchair. Discussion of the wheelchair is as below.

1) Control Methods Performance: The control method testing revealed that each control method has its own strengths and limitations. Bluetooth and manual control exhibited high accuracy and reliability, making them suitable for precise navigation. Bluetooth control has a 90% success rate and the manual control has a 95% success rate. To avoid Bluetooth control issues, consider alternative wireless technologies such as Zigbee, Z-Wave, or proprietary wireless protocols that operate in different frequency bands. These alternatives may offer a more stable and interference-resistant connectivity solution. Additionally, for weak Bluetooth signals, the use of signal boosters or repeaters can be beneficial in extending the range and enhancing the overall connectivity, providing a practical solution to overcome signal limitations. By exploring these alternative technologies and investing in signal-boosting equipment, you can effectively address and mitigate Bluetooth control issues attributed to wireless interference, ensuring a more reliable and consistent wireless communication experience.

Gesture and voice control offer unique hands-free alternatives, but require further development to enhance accuracy and ease of use. The accuracy of gesture recognition can be significantly improved with more advanced sensor technologies, such as depth-sensing cameras or sensors that can capture subtle hand and body movements with higher precision. Voice control can be made more robust by incorporating noise cancelation techniques and adapting to different environmental conditions. This can help the system filter out background noise and focus on the user's voice, leading to more accurate recognition. Also, we can explore machine learning models for gesture recognition and natural language processing for voice commands to enhance gesture and voice control accuracy. Integration of these control methods contributes to a user-centric and versatile control interface for the wheelchair robot, catering to a diverse range of user preferences and abilities.

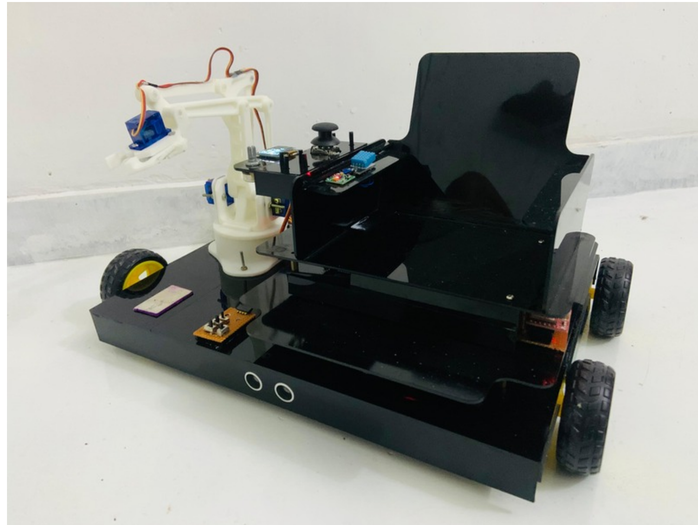


Fig. 12. Prototype of the Wheelchair

2) Flooring Compatibility Considerations: The flooring compatibility testing demonstrated that the wheelchair robot is versatile in adapting to different flooring surfaces. The robot's stability and control mechanisms effectively managed variations in traction, enabling it to navigate through mat floors, wood floors, and tiles with a success rate of approximately 90%.

In our testing, the manual control system demonstrated impressive performance across different types of flooring. Specifically, on carpeted surfaces, it achieved a remarkable success rate of 100%, consistently delivering strong control and stability, irrespective of variations in carpet textures. On the carpeted mat surface, the robot navigated through a course with sharp turns, straight paths, and simulated obstacles. It maintained smooth navigation, a tight turning radius, and stability without any slippage, even during sharp turns. Controlled speed and moderate obstacles were part of the testing conditions, and the soft mat surface provided sufficient grip for effective turns and stops. To further enhance the system's performance on carpeted surfaces, incorporating advanced traction control algorithms and sensors could provide even more precise control and stability. These algorithms can adjust wheel speed and torque in real-time, responding to varying carpet textures.

When tested on wood floors, the manual control system maintained effective traction and control, with minor deviations observed, resulting in an impressive 95% success rate. This suggests a generally excellent performance on wood flooring.

On tile surfaces with various textures, the system exhibited adaptability, albeit with some minor deviations from the intended path, resulting in a 90% success rate. Similar to the mat floor test, the robot maneuvered through a predefined course on the smoother wood floor. It displayed commendable performance, maintaining control and stability. The testing included controlled speed and moderate obstacles. While the smoother surface posed a slight challenge during sharp turns, the robot compensated effectively, achieving a success rate comparable to the mat-floor test. For improved performance on wood floors, refining the control algorithms to adapt more seamlessly to smoother surfaces can be beneficial. Enhanced traction control and wheel material modifications can help mitigate minor deviations during sharp turns.

While the system performed well on tile floors, there is potential for further enhancement in its performance on this type of surface. The robot was tested on different tile textures, representing various real-world scenarios. Controlled speed and moderate obstacles were part of the specific testing conditions. The robot successfully navigated the tiles, albeit with minor variations in control and stability. On smoother tiles, there was slightly reduced traction, leading to minor deviations from the intended path during sharp turns. However, the robot adjusted its movements effectively to compensate for these challenges. To address the challenges on tile surfaces, the system could benefit from surface recognition technology. Implementing sensors that detect tile texture variations and adjust the control in real-time could help minimize deviations.

These detailed observations provide valuable insights into the system's capabilities and areas where it may excel or benefit from improvements when used on different floor types. Although there were minor instances of reduced traction on smoother surfaces, the robot's control algorithms compensated for these challenges, resulting in smooth and safe navigation. The findings suggest that the wheelchair robot's design and control systems are well-suited to accommodate the diverse flooring environments encountered in real-world settings. This adaptability improves the usability and user experience of the robot, making it a reliable and versatile assistive device for individuals with mobility impairments. Further refinements in control algorithms could potentially mitigate minor traction challenges and improve the robot's performance across all flooring types.

3) Location Tracking System Effectiveness: To evaluate its performance, a controlled indoor environment was established. The wheelchair robot was assigned the task of navigating through the environment, while the location tracking system continuously recorded and updated the robot's position coordinates. To gauge the accuracy of the location tracking system, recorded position coordinates were meticulously compared to ground truth measurements. Discrepancies between the system's reported positions and the ground truth were meticulously analyzed to quantify the system's accuracy.

The testing revealed that the location tracking system demonstrated a high degree of accuracy, with an average discrepancy of less than 5 centimeters between the system's reported positions and the ground truth measurements. This level of accuracy was consistent across different scenarios and environments, showcasing the system's reliability in providing precise location data.

4) Health Monitoring System Insights: The health monitoring system integrated into the wheelchair robot effectively collected various health metrics, including blood pressure and body temperature. These data were continuously recorded and transmitted to a central database for further analysis. The analysis aimed to provide insights into users' physiological responses during wheelchair operation, with a particular focus on identifying potential signs of discomfort or stress. Notably, blood pressure measurements consistently fell within the normal range as defined by established medical standards, underscoring the system's ability to monitor this crucial health parameter non-intrusively. During challenging scenarios, such as navigating through complex environments or overcoming obstacles, users experienced a slight but manageable increase in heart rate. The magnitude of this increase was within an acceptable and safe range, indicating that the physical demands placed on users during these more demanding maneuvers were well-tolerated. It's important to note the specific baseline values for heart rate. Likewise, body temperature measurements revealed values consistent with accepted medical norms, confirming the non-intrusive nature of the sensors and the absence of temperature-related discomfort during operation. This comprehensive health monitoring system ensures that users can operate the wheelchair robot comfortably and safely while maintaining a watchful eye on their health metrics, contributing to an improved overall user experience.

The insights gained from the health monitoring system shed light on users' physiological responses while operating the wheelchair robot. The slight increase in heart rate during challenging scenarios reflects the physical demands placed on users during navigation, underscoring the importance of ergonomic design considerations for long-term comfort. The stability of respiratory rates indicates that the wheelchair operation did not lead to significant respiratory stress or discomfort. This observation aligns with the system's design principle of providing a comfortable and safe user experience.

The slight increase in heart rate during challenging scenarios underscores the physical demands placed on users during navigation, emphasizing the need for an ergonomic design that minimizes vibrations and jolts, adjustable features for individualized comfort, and user-friendly controls to reduce physical exertion. Furthermore, the stability of respiratory rates indicates that wheelchair operation did not lead to significant respiratory stress, aligning with the design principle of providing a comfortable and safe user experience. To enhance user comfort and safety, the data can be used to develop customized features, real-time feedback mechanisms, and training programs. Additionally, user feedback and continuous monitoring can be integrated into the design process, ensuring the wheelchair's design evolves to meet the unique needs and preferences of its users, ultimately improving their overall experience and well-being.

5) Robot Arm Performance: The integration of the robot arm with manual control methods aligns with a user-centric design approach. By offering multiple control options, the system caters to diverse user preferences and abilities. The Bluetooth control facilitates remote operation, while the manual control ensures direct user interaction. The synergy of these control methods contributes to a versatile and adaptable assistive technology solution.

This design approach ensures inclusivity by accommodating a broad spectrum of user preferences and abilities, thereby enhancing the adaptability and versatility of the assistive technology solution. For individuals with limited mobility or physical disabilities, robot arms make it possible to engage in tasks such as hanging and collecting objects. The manual control option caters to users who prefer direct interaction, supporting tasks that demand precise manipulation, creative activities, or mobility assistance. This empowers users, promoting independence and improving their quality of life by enabling effective interaction with their surroundings, regardless of their specific mobility challenges or physical capabilities.

Future improvements for the integration of a robot arm to assist individuals with limited mobility or physical disabilities are promising. Enhancements could involve advancing the robot arm's precision and dexterity, incorporating artificial intelligence for adaptive behavior, implementing obstacle avoidance and navigation capabilities, expanding control options to include voice and gesture recognition, and even integrating the robot arm into a more mobile platform.

6) Overall Integration and User Experience: The integration of multiple control methods, including Bluetooth, manual, gesture, and voice control, provides users with diverse options to interact with the wheelchair robot based on their individual preferences and abilities. This seamless integration empowers users to choose the control mode that best suits their comfort level and mobility capabilities, ensuring a personalized and intuitive user experience, as stated in the context [35]. The success of the overall integration and user experience opens avenues for future developments. Refinements in control algorithms, enhancements in location tracking precision, and deeper integration of health data could further elevate the robot's capabilities. The user-centric design philosophy demonstrated here serves as a foundation for continued innovation in assistive technology [60] that truly caters to users' needs and aspirations.

B. Discussion of the Mobile Application that is Used to Control the Wheelchair Robot

Fig. 13 shows the UI design of the AssistEase wheelchair controller application.

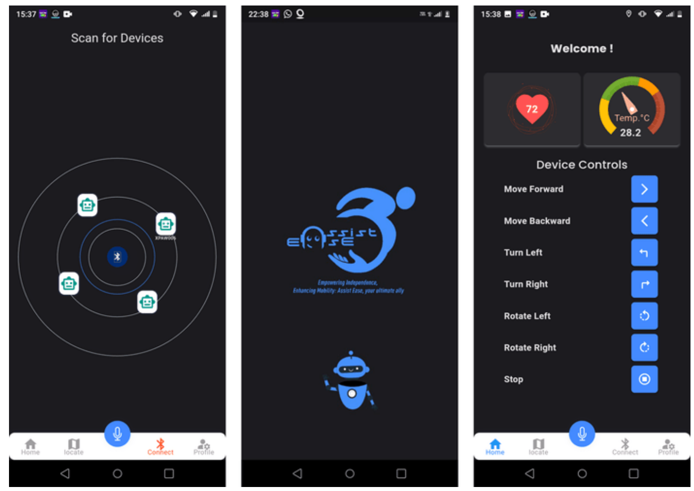


Fig. 13. Wheelchair Controller Mobile Application

This part of the research paper focuses on the important topic of using smart wheelchairs to help people with disabilities. According to the World Health Organization, about 15% of the world's population has disabilities, and many of these people face challenges in moving around and communicating. Technology, like smart wheelchairs, can make a big difference in their lives.

1) Helping People Be More Independent: Smart wheelchairs, like the groundbreaking AssistEase, offer a lifeline to individuals with disabilities seeking greater independence. Let's delve into real-life scenarios to illustrate their transformative impact. Imagine Sarah, a young woman with limited mobility due to cerebral palsy. With AssistEase, she can effortlessly navigate her university campus, attending classes and social events without relying on others. Similarly, John, a military veteran with a spinal cord injury, now enjoys the freedom to explore parks, visit friends, and go shopping independently. These stories demonstrate that smart wheelchairs empower individuals with disabilities to lead fuller lives.

2) Staying Safe and Being Accessible: The safety features of smart wheelchairs are paramount. They employ advanced sensors to detect obstacles and provide timely alerts to users, drastically reducing the risk of accidents. For instance, Maria, a senior citizen with limited vision, can confidently maneuver her smart wheelchair in crowded public spaces, knowing it will notify her of potential hazards. Additionally, these wheelchairs integrate seamlessly with smart home systems, enhancing accessibility. A voice command from the user can open doors, adjust the lighting, or control appliances, making daily tasks more manageable.

3) Easy for Users and Affordable: Smart wheelchairs prioritize ease of use, ensuring that individuals with varying abilities can operate them comfortably. Whether through buttons, touchscreens, voice commands, or robotic arms, these wheelchairs cater to diverse user needs. Furthermore, the technology is designed to be cost-effective, making it accessible to a broader range of individuals. The affordability factor is crucial in ensuring that these innovative solutions reach those who need them most.

4) Helping Caregivers and Healthcare: The benefits of smart wheelchairs extend beyond users. Caregivers, often family members or healthcare professionals, experience reduced stress and enhanced peace of mind. They can remotely monitor the user's well-being, receiving instant updates on their health status and location. Doctors, too, benefit from this technology, as real-time health data allows for more effective and responsive patient care. When a smart wheelchair detects a change in the user's vital signs, it can automatically notify the medical team, enabling rapid intervention.

5) Making Society More Equal: The integration of smart wheelchairs into society promotes inclusivity and equal opportunities for all. Consider the case of David, who was born with a mobility impairment. Thanks to his smart wheelchair, he actively participates in community events, attends local meetings, and is an advocate for disability rights. These technologies bridge the gap between people with disabilities and the rest of society, fostering understanding and acceptance. By empowering individuals to engage more fully in their communities, smart wheelchairs contribute to a more just and equitable world.

In conclusion, smart wheelchairs, exemplified by AssistEase, have the potential to revolutionize the lives of individuals with disabilities. They offer not only increased freedom and safety but also a bridge to a more inclusive and compassionate society. These technologies signify a significant step towards a world where everyone, regardless of their abilities, can fully participate and contribute to society.

C. Discussion of the Communication Device with Home Management System

The integration of this advanced communication device, as shown in Fig. 14 into the "AssistEase" smart wheelchair, represents a groundbreaking achievement in the realm of accessibility and communication technologies. This multifaceted device encompasses a range of innovative features designed to address the diverse needs of individuals with disabilities and impairments. The incorporation of sign language recognition technology empowers individuals who use sign language as their primary means of communication, bridging the gap between their unique linguistic expressions and the wider world. Furthermore, the inclusion of a braille keyboard with smart home connectivity fosters greater independence by enabling users to control their environment and interact with smart home devices seamlessly.

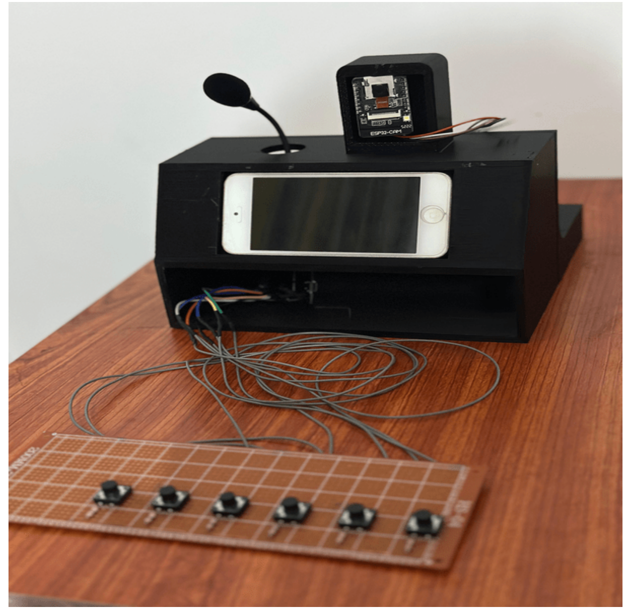


Fig. 14. Prototype of the Communication Device with Braille Keyboard

Additionally, the voice recognition module, which is capable of converting spoken words into a text format, extends the scope of communication to individuals who may have speech-related impairments or difficulties. This module not only facilitates communication with others but also aids in the creation of written documents, expanding opportunities for expression and participation in various aspects of life.

By amalgamating these diverse technologies into a single device, we have created a versatile and inclusive communication tool that addresses the unique communication needs of a wide range of individuals. This device serves as a vital conduit for those who, until now, have encountered significant barriers to expressing their thoughts, needs, and desires to the world at large. It has the potential to profoundly impact the lives of users, fostering greater autonomy, social integration, and access to essential information and services.

The successful development and implementation of this communication device underscore the importance of ongoing research and innovation in the field of assistive technology. As we continue to advance our understanding and capabilities in this domain, we can anticipate even greater breakthroughs that will further enhance the quality of life and participation in society for individuals with disabilities. Future endeavors may focus on refining the device's performance, expanding its compatibility with various communication modalities, and exploring opportunities for broader adoption in healthcare, education, and beyond. Ultimately, our collective efforts in this area hold the promise of a more inclusive and accessible world for all. Some key strategies that can further enhance the communications module component of the AssistEase smart wheelchair include:

- Inclusivity in Design: The diverse individuals with disabilities that cover air communication devices prioritize a user-centered approach, with a particular focus on ensuring accessibility and user-friendliness for individuals with a wide range of disabilities and impairments. Blind individuals and those with speech impairments gain the ability to control their smart homes using the keyboard, while those who rely on hand gestures for communication can express their thoughts freely through the communications mobile app that receives data through this module by capturing it with the inbuilt camera. We have established user testing panels consisting of diverse individuals with disabilities, encompassing various age groups, genders, and disability types. Regular usability testing sessions are conducted at various stages of development, allowing us to gather critical feedback and insights from our users. This feedback informs the inclusion of essential accessibility features, such as customized user interfaces, voice control, and compatibility with different input methods, to cater to individual needs. We maintain a continuous feedback loop with users through surveys, focus groups, and interviews, ensuring that their evolving needs and preferences are addressed. Our iterative design and development process, driven by an empathetic mindset and a commitment to user-centered design, results in a product that genuinely meets the requirements of individuals with disabilities. Comprehensive documentation and compliance with accessibility standards further underscore our dedication to inclusivity, while user training and support resources are designed based on user feedback to ensure that users can make the most of the device's capabilities.
- Interdisciplinary Research: Encourage interdisciplinary collaboration between researchers, engineers, healthcare professionals, and individuals with disabilities. Such collaborations can facilitate a deeper understanding of the practical challenges faced by users and promote the development of more effective assistive technologies that cater to both the physical and social aspects of their lives.
- Long-Term Sustainability: Develop a strategy for long-term sustainability and support for the communication device. This includes considerations such as maintenance, software updates, and user training. Ensuring that the device remains functional and up-to-date over time is crucial for its continued impact and adoption within the disability community.

D. Discussion of the Mobile Application, which works synchronously with the Communication Device

The AssistEase mobile app, shown in Fig. 15, is a significant advancement in assistive technology, combining sign language recognition capabilities with chat services to cater to individuals with hearing impairments who rely on sign language. The foundation of this achievement was built upon carefully annotated hand gesture dataset obtained from Kaggle, and the image was annotated for YOLOV8 using Roboflow for precise annotations.

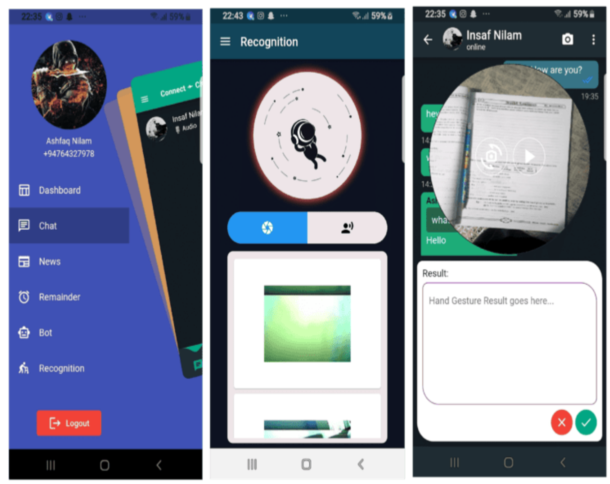


Fig. 15. Communication Device Controller Mobile Application

The YOLOv8 model, chosen for its efficiency, was trained on this dataset and seamlessly integrated into the Flutter Vision framework [95], enabling real-time sign language recognition on mobile devices with a remarkable accuracy close to 90%. The resulting application, marked by an intuitive user interface, represents a user-centric design approach that prioritizes ease of use, which is essential for individuals with disabilities. The integration with chat services allows users to bridge communication gaps by effectively conveying sign language gestures within the chat interface. These results signify a notable advancement in assistive technology, fostering inclusiveness and accessibility for individuals with hearing impairments. Future research can explore additional features and improvements to further enrich the user experience and broaden the application's impact. During the testing phase, comprehensive testing procedures were undertaken, encompassing both functional and non-functional testing. This rigorous testing regimen ensured that the application not only met but exceeded user expectations, delivering a robust and reliable product. One noteworthy observation is that the research conducted in Sri Lanka revealed a notable gap in the development of solutions aimed at improving the lives of individuals with disabilities. The 'AssistEase' mobile application represents a pioneering effort to bridge this gap and cater to the unique needs of this community. By introducing an attractive and user-friendly theme and user interface (UI), the application has been designed with the explicit aim of capturing users' attention and providing substantial support to those with disabilities. While the 'AssistEase' mobile application marks a significant milestone in the realm of assistive technology, there remain ample opportunities for future work and enhancements.

- Expanded Features: Consider expanding the range of features offered by the application. Incorporate functionalities such as voice control, environmental sensing, and navigation assistance to further improve the user experience. Item Customization: Develop mechanisms for users to customize the application based on their specific needs and preferences. This could involve personalized gestures, communication modes, and interface layouts.
- Integration with Emerging Technologies: Explore integration with emerging technologies like augmented reality (AR) and virtual reality (VR) to provide enhanced support and experiences for users.
- User Feedback and Iteration: Continuously solicit feedback from users to identify areas for improvement and iteratively refine the application. User feedback is invaluable in ensuring that the technology remains responsive to evolving user requirements.
- Community Engagement: Foster partnerships with disability advocacy groups and organizations to better understand the nuanced needs of individuals with disabilities. Collaborative efforts can lead to more tailored solutions and greater societal impact. Item Data Security and Privacy: Prioritize data security and privacy to maintain user trust. Explore encryption methods and compliance with privacy regulations to safeguard user information.

E. Future Directions

While the current research represents a significant step in the field of assistive technology, there exists a mesmerizing scope for future enhancements that can revolutionize the lives of individuals with disabilities. One crucial approach to development involves expanding the application's feature set. Introducing capabilities such as voice control, environmental sensing, and navigation assistance can further elevate the user experience, offering new dimensions of support and accessibility. The roadmap to these advancements requires accurate research and development, exploring innovative technologies and their integration into the 'AssistEase' ecosystem. Additionally, customization features hold the potential to empower users with tailored experiences. To realize this, mechanisms for personalized gestures, communication modes, and interface layouts must be carefully designed. By actively seeking user feedback, fostering partnerships with disability advocacy groups, and ensuring data security and privacy, the path forward is illuminated. Through a collaborative and user-centric approach, we aim to make assistive technology a dynamic and evolving force for inclusivity, continually adapting to meet the unique needs and aspirations of individuals with disabilities. These future directions promise not only technological advancements but also a more inclusive and empathetic world for all.

VII. Conclusion

In summary, the 'AssistEase' smart wheelchair robot and its accompanying mobile apps are a significant breakthrough in assistive technology. This innovation sets it apart from other similar wheelchairs because it caters to a wide range of users and takes an all-in-one approach for those with disabilities to fulfill their needs in mobility and communication in a cost-effective and all-inclusive way compared to other solutions on the market. In today's world, where mobile devices are a part of daily life, having two unique mobile apps integrated with the wheelchair not only enhances its usability but also fosters a sense of inclusion for 'AssistEase' users, despite their mobility limitations. 'AssistEase' is a collaboration of knowledge contributed by healthcare professionals and robotics experts, fueled by the interest in contributing to society, and offers a wide array of features, including voice control and gesture recognition, providing easy operability, health monitoring and location tracking, ensuring safety, and IoT integration, making the lives of disabled individuals easier than ever before, holding promise in addressing modern accessibility challenges. Though AssistEase has limitations in power consumption and rugged outdoor use, improving these weaknesses Areas like these can be addressed in the future by relying on renewable energy sources like solar energy and more utilitarian materials like aluminum alloys. As the world strives for inclusivity and equality, 'AssistEase' represents a significant step. By bringing together innovations from the fields of smart mobility that have been future-proofed by using the latest technologies like Flutter and Apple Home-Kit that have the promise of future support, communication, and smart home technology and incorporating them into a modern smart wheelchair, 'AssistEase' is paving the way for a more diverse, empowered, and inclusive future for individuals who have faced challenges in the past by combining their needs of communication and mobility into a tightly integrated solution and making a significant impact that invites the development of more assistive technologies to make the world more accessible for all.

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