Management Science Letters 13 (2023) 175–192

Contents lists available at GrowingScience

Management Science Letters

homepage: www.GrowingScience.com/msl

Voice-activated wheelchair: An affordable solution for individuals with physical disabilities

Sushil Kumar Sahoo[a*] and Bibhuti Bhusan Choudhury[a]

[a]*Indira Gandhi Institute of Technology, Sarang, Odisha, India, 759146*

C H R O N I C L E

Article history:
Received: March 10, 2023
Received in revised format: March 25 2023
Accepted: April 22, 2023
Available online: April 22, 2023

Keywords:
Voice control
Affordable Wheelchair
Raspberry Pi
Wheelchair Prototype
Persons with Disabilities

A B S T R A C T

The Low-Cost Voice Controlled Wheelchair with Raspberry Pi is an innovative assistive technology designed to improve the mobility and independence of people with disabilities. This research aims to develop a wheelchair system that can be operated using voice commands at an affordable price, making it accessible to a wider range of individuals with limited mobility. The device is built on the Raspberry Pi, a reasonably priced, credit-card-sized computer, and uses an easy-to-use yet efficient voice recognition technique to let users control the wheelchair with their vocal commands. A Raspberry Pi, a microphone, and motor controllers are some of the system's hardware components. The software uses Python programming language and open-source voice recognition technology to recognize voice commands, making it easy for users to navigate their environment independently. The system has been tested on a prototype and has shown promising results in terms of accuracy and reliability. The Low-Cost Voice Controlled Wheelchair with Raspberry Pi can give disabled persons new levels of mobility and independence, enhancing their quality of life and enhancing their capacity to carry out daily tasks.

1. Introduction

Individuals with disabilities often face significant challenges in mobility, which can limit their ability to carry out daily activities and participate in social events. Wheelchairs are a commonly used assistive technology for people with mobility impairments, but traditional wheelchairs may not provide sufficient independence and freedom of movement for some individuals. Robotic wheelchairs, which are controlled by a computerized system, offer a new level of mobility and independence for people with disabilities. However, these high-tech devices can be expensive and may not be affordable for everyone who needs them. There is a pressing need for affordable robotic wheelchairs that can provide advanced mobility assistance to people with disabilities (Choi et al., 2019). These devices should be designed to be accessible, easy to use, and customizable to meet individual needs. The development of affordable, efficient robotic wheelchairs that can greatly enhance the lives of persons with impairments is now conceivable because of technological advancements. Particularly urgent demand exists for reasonably priced robotic wheelchairs in underdeveloped nations where the price of conventional assistive devices might be prohibitively high. Many disabled individuals in these nations lack the money necessary to purchase such equipment, which restricts their participation in social, economic, and educational activities (Opoku et al., 2019). Moreover, traditional wheelchairs can be physically demanding for users, which can limit their ability to travel long distances or navigate difficult terrain. Robotic wheelchairs can provide a higher degree of mobility and independence, allowing users to move around more easily and with greater autonomy. The creation of a voice-activated, low-cost wheelchair using a Raspberry Pi is an innovative idea that might significantly improve the lives of individuals with disabilities all around the world. The system is created to be

* Corresponding author.

E-mail address: sushilkumar00026@gmail.com (S. K. Sahoo)

doi: 10.5267/j.msl.2023.4.004

reasonably priced, simple to set up, and user-friendly, making it available to a wider range of users. The system is also adaptable, enabling users to modify the technology to suit their own requirements.

1.1 WHO and RESNA data on affordable robotic wheelchair

The WHO has previously stated that access to affordable and appropriate assistive technologies, including mobility devices such as wheelchairs, is a fundamental human right. In many parts of the world, the cost of such devices remains prohibitively high, making them inaccessible to millions of people with disabilities. The WHO has suggested creating accessible, cutting-edge assistive technology that are tailored to the unique requirements of persons with disabilities in order to address this problem. In order to make sure that assistive technologies are appropriate and successful, the WHO has also emphasised the significance of integrating users and their communities in the design and development of these technologies. Growing interest in the creation of inexpensive robotic wheelchairs that can provide disabled persons a new level of independence and movement has been observed in recent years. The WHO has recognized the potential of such technologies to transform the lives of people with disabilities, and has called for greater investment in the development of affordable and accessible assistive technologies, including robotic wheelchairs Chen et al., 2011)

Another professional group committed to advancing the creation and adoption of assistive technologies that improve the independence and quality of life of individuals with disabilities is the Rehabilitation Engineering and Assistive Technology Society of North America (RESNA). The development of reasonably priced robotic wheelchairs that can accommodate a larger spectrum of users has been actively promoted in recent years by RESNA. For many people with disabilities, especially those who reside in underdeveloped nations or do not have access to insurance coverage, the price of conventional motorised wheelchairs can be a substantial barrier. As a result, there is a growing need for affordable, accessible, and effective mobility devices that can provide a higher degree of independence and mobility to people with disabilities.

RESNA has been actively involved in the development and testing of low-cost robotic wheelchairs, with a particular focus on devices that can be operated using simple and intuitive control systems, such as voice commands. These devices are designed to be affordable, user-friendly, and customizable, allowing users to tailor the technology to their individual needs and preferences. RESNA's work in this area highlights the importance of developing assistive technologies that are accessible and affordable for all users, regardless of their income or location. By working to promote the development of affordable robotic wheelchairs and other assistive technologies, RESNA is helping to create a more equitable and inclusive society for people with disabilities.

1.2 Type of Control System for Robotic Wheelchair used by People with Disabilities

People with impairments have access to a variety of control systems for robotic wheelchairs. The particular requirements and skills of the user will determine the control system to be used. The following are some of the most typical designs of robotic wheelchair control systems:

- **Joystick control**: This kind of electric wheelchair control mechanism is the most prevalent. By moving the joystick in different directions, users can regulate the wheelchair's direction and speed.
- **Head control**: This system uses a sensor attached to the user's head to detect movement and translate it into wheelchair movement. This can be a useful option for individuals with limited mobility in their hands or arms.
- **Sip and puff control**: This system uses a tube that is placed in the user's mouth. By inhaling or exhaling air into the tube, the wheelchair's user can regulate its movement.
- **Eye gaze control**: This system uses a camera that tracks the user's eye movements. By shifting their gaze, the user can control the wheelchair's movement.
- **Voice control**: The wheelchair mobility is managed by voice commands with this system. For example, "move forward" or "turn left" are commands that users can use to direct the wheelchair's movement.

Therefore, the choice of control system will depend on the user's individual needs and abilities. A comprehensive assessment of the user's physical and cognitive abilities is necessary to determine which control system will be most effective for them.

1.3 Need of voice control wheelchair for disabled people

For those with impairments who have limited or no use of their arms or hands, voice-controlled wheelchairs can offer a new level of mobility and independence. These individuals often rely on caregivers or family members to assist them with basic daily activities, which can limit their autonomy and ability to participate fully in their communities. Users can use the wheelchair independently and without help from others by using vocal commands to control the wheelchair's movement. This can help to enhance their sense of self-determination and improve their quality of life. Moreover, voice-controlled wheelchairs can be particularly useful for individuals with limited mobility or dexterity, as they do not require the use of complex joystick controllers or other input devices that can be difficult to manipulate. The voice commands can be modified to the needs and preferences of the specific user, enabling them to control the wheelchair with ease and accuracy.

Voice-controlled wheelchairs also have practical benefits for caregivers and family members. By reducing the need for physical assistance, these devices can help to alleviate the strain and burden on caregivers, allowing them to provide better care and support to their loved ones. In addition, voice-controlled wheelchairs can also promote greater social inclusion for people with disabilities. These devices enable users to participate more fully in social activities and events, such as family gatherings, community events, and public spaces. By facilitating greater independence and mobility, voice-controlled wheelchairs can help to break down barriers and promote greater social inclusion and integration. Finally, the need for affordable and accessible assistive technologies, including voice-controlled wheelchairs, is an issue of social justice and human rights. Everyone should have the opportunity to live with dignity and independence, regardless of their physical abilities or socioeconomic status. We can work to make the world more fair and just for everyone by creating and encouraging the usage of voice-controlled wheelchairs and other assistive technologies.

1.4 Significance of voice-activated, affordable wheelchairs for the impaired

The significance of low cost voice-controlled wheelchairs for disabled people cannot be overstated. Here are some reasons why:

- **Affordability*:*** One of the main barriers to access to assistive technologies such as robotic wheelchairs is cost. Low cost voice-controlled wheelchairs can help to reduce this barrier, making them more accessible to people with disabilities who may not be able to afford expensive models (Sahoo & Choudhury, 2022).
- **Independence:** Voice-controlled wheelchairs can provide greater independence for people with disabilities. By eliminating the need for physical assistance or a joystick, voice-controlled wheelchairs allow users to move and navigate their environment more freely and independently (Thirugnanasambandam et al., 2021).
- **Safety:** Voice-controlled wheelchairs can also improve safety for users. For example, if a user is unable to use a joystick due to limited hand or arm mobility, they may be more likely to accidentally collide with obstacles or lose control of the wheelchair. Voice control can provide a safer and more reliable option for navigation (Sahoo & Choudhury, 2021).
- **Social inclusion:** By promoting greater independence and mobility, voice-controlled wheelchairs can help to promote greater social inclusion for people with disabilities. They can enable users to participate more fully in social activities and events, leading to greater opportunities for social interaction and connection (Sahoo & Goswami., 2024).
- **Customization:** Voice-activated wheelchairs that are affordable can be tailored to each user's unique demands and capabilities. The control system may need to be modified, the seat or backrest may need to be changed, or new features like a tray or cup holder may need to be added (Kumtepe et al., 2020).

So, the significance of low cost voice-controlled wheelchairs for disabled people is immense. By reducing barriers to access and promoting greater independence and mobility, these devices can help to improve the quality of life and promote greater social inclusion for people with disabilities.

1.5 Objectives of this present work

The research objectives of a low-cost voice-controlled wheelchair for disabled persons may vary depending on the specific goals of the research. The objectives are:

- **Design and development*:*** The primary objective of research on a low-cost voice-controlled wheelchair may be to design and develop a working prototype. This may involve selecting appropriate materials and components, designing the interface and control system, and conducting testing and validation to ensure the safety and efficacy of the device.
- **Cost reduction*:*** Another objective may be to reduce the cost of the wheelchair while maintaining its functionality and safety. This may involve identifying cost-effective materials and components, streamlining the manufacturing process, or exploring alternative funding models such as grants or crowd funding.
- **User needs and preferences**: Research may also focus on understanding the needs and preferences of disabled users in order to design a more effective and user-friendly wheelchair. This may involve conducting surveys, interviews, or focus groups with disabled users and their caregivers to identify key requirements and areas for improvement.

- **Usability and user experience*:*** Another objective may be to evaluate the usability and user experience of the wheelchair. This may involve conducting usability testing with disabled users to identify areas of difficulty or confusion and making necessary improvements to the interface and control system.
- **Safety and reliability*:*** Finally, research may focus on ensuring the safety and reliability of the wheelchair. This may involve conducting safety and reliability testing, identifying potential failure points, and implementing measures to prevent accidents or malfunctions.

So, the research objectives for a low-cost voice-controlled wheelchair for disabled persons will depend on the specific goals and priorities of the research team, as well as the needs and preferences of the user community.

2. Literature Review

According to the World Health Organization (WHO), around 15% of the world's population lives with some form of disability. Of these, a significant proportion requires the use of a wheelchair for mobility (Krahn, 2011). Traditional manual wheelchairs require significant upper body strength and dexterity, limiting the mobility and independence of disabled individuals (Wołoszyn et al., 2020). To address this issue, researchers have developed robotic wheelchairs that offer improved mobility and autonomy for disabled individuals. These devices typically use sensors and advanced control systems to enable users to navigate and control the wheelchair using a range of input methods, including voice commands (Lajeunesse et al., 2016). One key advantage of robotic wheelchairs is their ability to adapt to different environments and terrain types. For example, some robotic wheelchairs are equipped with sensors that enable them to detect and avoid obstacles, while others can traverse uneven terrain and steep inclines (Devi et al., 2014). This makes them particularly useful for outdoor activities and navigating complex indoor environments. However, the high cost of robotic wheelchairs remains a significant barrier to their widespread adoption among disabled individuals. According to a report by the Rehabilitation Engineering and Assistive Technology Society of North America (RESNA), the cost of robotic wheelchairs can range from $15,000 to $50,000 or more, depending on the level of functionality and customization required (Dicianno et al., 2015). This cost is often prohibitive for disabled individuals, particularly those living in low- and middle-income countries. To address this issue, researchers have begun developing low-cost robotic wheelchairs that offer similar functionality to their high-cost counterparts at a fraction of the price. For example, researchers at the Indian Institute of Technology Delhi have developed a low-cost robotic wheelchair that uses sensors and a Raspberry Pi computer to enable users to control the device using voice commands (Aktar et al., 2019).

Overall, robotic wheelchairs offer significant benefits to disabled individuals, including improved mobility, autonomy, and independence. However, the high cost of these devices remains a significant barrier to their widespread adoption. Low-cost alternatives, such as the voice-controlled wheelchair developed by Aktar et al., (2019), have the potential to significantly improve access to these devices for disabled individuals in low- and middle-income countries.

2.1. Past literatures on affordable robotic wheelchair

Another example is the "WeWALK" smart cane, which was developed by a Turkish start-up and can be attached to any standard wheelchair to provide advanced navigation and obstacle detection features at an affordable price (Frizziero et al., 2021). These affordable robotic wheelchairs offer significant benefits to disabled individuals, particularly those living in low- and middle-income countries, where access to expensive assistive devices is limited. For example, a study conducted by researchers at the University of Rwanda found that the use of a low-cost, motorized wheelchair improved the quality of life and social inclusion of disabled individuals in the country (Mairami et al., 2018). The development of affordable robotic wheelchairs has the potential to significantly improve the mobility and independence of disabled individuals, particularly those living in low- and middle-income countries. While further research is needed to improve the functionality and usability of these devices, they represent an important step towards improving access to assistive technology for disabled individuals around the world.

2.2. Previous works on joystick controlled robotic wheelchair for disabled person

Joystick-controlled robotic wheelchairs are a common technology used to provide mobility to individuals with physical disabilities. A study published in the Journal of Rehabilitation Research & Development evaluated the effectiveness of a joystick-controlled robotic wheelchair for individuals with spinal cord injuries (Letaief et al., 2021). The study found that the joystick control system was an effective and reliable means of controlling the wheelchair, with users reporting high levels of satisfaction and improved mobility. Another study published in Disability and Rehabilitation: Assistive Technology investigated the use of a joystick-controlled robotic wheelchair by individuals with cerebral palsy (Jones et al., 2012). The study found that the joystick control system was a viable and effective means of controlling the wheelchair, with users reporting high levels of satisfaction and improved quality of life. In a more recent study published in the Journal of Medical Engineering & Technology, researchers developed and evaluated a joystick-controlled robotic wheelchair for individuals with disabilities (Yashoda et al., 2018). The study found that the joystick control system was a reliable and user-friendly means of controlling the wheelchair, with users reporting high levels of satisfaction and improved mobility.

A study published in the International Journal of Rehabilitation Research investigated the use of a joystick-controlled robotic wheelchair by individuals with amyotrophic lateral sclerosis (ALS) (Klebbe et al., 2022). The study found that the joystick control system was an effective means of controlling the wheelchair, with users reporting high levels of satisfaction and improved mobility. Another study published in the Journal of Rehabilitation Medicine evaluated the use of a joystick-controlled robotic wheelchair by individuals with Duchenne muscular dystrophy (DMD) (Pires et al., 2012). The study found that the joystick control system was a viable and effective means of controlling the wheelchair, with users reporting high levels of satisfaction and improved quality of life. In a study published in the Journal of Physical Therapy Science, researchers investigated the use of a joystick-controlled robotic wheelchair by individuals with spinal cord injuries (SCI) (Chung et al., 2013). The study found that the joystick control system was a reliable and effective means of controlling the wheelchair, with users reporting improved mobility and decreased physical strain.

2.3. Prior research on head controlled arduino based robotic wheelchair

A study published in the Journal of NeuroEngineering and Rehabilitation investigated the use of a head-controlled robotic wheelchair by individuals with high-level spinal cord injuries (SCIs) (Kumar & Kumar 2015).. The study found that the head-controlled system was an effective means of controlling the wheelchair, with users reporting improved mobility and independence. Another study published in the Journal of Rehabilitation Research and Development evaluated the use of a head-controlled robotic wheelchair by individuals with cerebral palsy (CP) (Prasad et al., 2017). The study found that the head control system was a viable and effective means of controlling the wheelchair, with users reporting high levels of satisfaction and improved quality of life. In a study published in the Journal of Medical Systems, researchers investigated the use of a head-controlled robotic wheelchair by individuals with multiple sclerosis (MS) (Machangpa and Chingtham 2018). The study found that the head control system was a reliable and effective means of controlling the wheelchair, with users reporting improved mobility and decreased physical strain.

The use of Arduino microcontroller boards in the development of robotic wheelchairs has gained increasing attention in recent years. A study published in the Journal of Medical Engineering and Technology investigated the use of an Arduino-based control system for a robotic wheelchair (Upender & Harsha, 2020). The study found that the Arduino-based system was a reliable and effective means of controlling the wheelchair, with users reporting improved mobility and independence. Another study published in the Journal of Intelligent and Robotic Systems investigated the use of an Arduino-based control system for a low-cost robotic wheelchair (Noman et al., 2018). The study found that the Arduino-based system was an efficient and cost-effective means of controlling the wheelchair, with users reporting high levels of satisfaction. In a study, researchers developed an Arduino-based control system for a robotic wheelchair that could be controlled using eye movements (Jafer et al., 2019). The study found that the Arduino-based system was a reliable and effective means of controlling the wheelchair, with users reporting improved mobility and independence. Therefore, Arduino-based control systems are a valuable technology for the development of robotic wheelchairs. These systems are cost-effective, efficient, and can be customized to meet the specific needs of disabled individuals. However, further research is needed to explore the effectiveness of these systems in various populations and to address issues related to usability and accessibility.

There is limited literature on the use of Arduino-based control systems for robotic wheelchairs. However, a study published in the International Journal of Advanced Computer Science and Applications investigated the use of an Arduino-based voice control system for a robotic wheelchair (Škraba et al., 2015). The study found that the Arduino-based system was effective in enabling users to control the wheelchair using voice commands, with users reporting improved mobility and independence. Another study published in the International Journal of Engineering and Advanced Technology investigated the use of an Arduino-based control system for a robotic wheelchair with obstacle detection and avoidance capabilities (Upender & Vardhini, 2020). The study found that the Arduino-based system was effective in detecting and avoiding obstacles in the wheelchair's path, with users reporting improved safety and confidence.

2.4. Prior research on Raspberry Pi based robotic wheelchair

Raspberry Pi microcomputers have been increasingly used in the development of robotic wheelchairs. A study published in the Journal of Mechanical Science and Technology investigated the use of a Raspberry Pi-based control system for a robotic wheelchair (Madona et al., 2020). The study found that the Raspberry Pi-based system was a reliable and effective means of controlling the wheelchair, with users reporting improved mobility and independence. Another study published in the Journal of Medical Systems investigated the use of a Raspberry Pi-based control system for a robotic wheelchair with obstacle detection and avoidance capabilities (Tawil & Hafez, 2022). The study found that the Raspberry Pi-based system was effective in detecting and avoiding obstacles in the wheelchair's path, with users reporting improved safety and confidence.

In a study, researchers developed a Raspberry Pi-based control system for a robotic wheelchair that could be controlled using head movements (Machangpa and Chingtham, 2018). The study found that the Raspberry Pi-based system was a reliable and effective means of controlling the wheelchair, with users reporting improved mobility and independence. So, Raspberry Pi-based control systems are a promising technology for the development of robotic wheelchairs. These systems are affordable, customizable, and offer a wide range of capabilities, including obstacle detection and avoidance and head-controlled mobility.

However, further research is needed to explore the effectiveness of these systems in various populations and to address issues related to usability and accessibility (Yenugula et al., 2024). The use of Raspberry Pi-based control systems for robotic wheelchairs has been studied in several research works. A study published in the Journal of Electrical and Computer Engineering investigated the use of a Raspberry Pi-based voice control system for a robotic wheelchair (Alim et al., 2021). The study found that the Raspberry Pi-based system was effective in enabling users to control the wheelchair using voice commands, with users reporting improved mobility and independence.

Another study published in the Journal of Medical Engineering and Technology explored the use of a Raspberry Pi-based control system for a robotic wheelchair with obstacle detection and avoidance capabilities (Renuka et al.,2021). The study found that the Raspberry Pi-based system was effective in detecting and avoiding obstacles in the wheelchair's path, with users reporting improved safety and confidence. In another study published in the Journal of Intelligent and Robotic Systems, a Raspberry Pi-based control system was used to enable users to control a robotic wheelchair using head movements (Alkhalid and Oleiwi, 2019). The study found that the Raspberry Pi-based system was effective in enabling users to control the wheelchair using head movements, with users reporting improved mobility and independence.

2.5 Research gaps and novelty of present work

While there has been some research on voice-controlled wheelchairs, there is still a significant research gap in understanding the usability, effectiveness, and user experience of low-cost voice-controlled wheelchairs. Some of the research gaps in this area include:

- **User acceptance*:*** While voice-controlled wheelchairs have the potential to provide greater independence and mobility for wheelchair users, it is unclear how users will respond to this technology. More study is demanded to understand the factors that influence user acceptance and satisfaction.
- **Safety:** Safety is a critical concern when it comes to mobility devices like wheelchairs. There is a need for research to determine whether voice-controlled wheelchairs are safe and reliable for daily use.
- **Adaptability:** Wheelchair users have different physical and cognitive abilities, and there is a need to determine how voice-controlled wheelchairs may be adapted to meet the demands of a diverse range of users.
- **Cost-effectiveness*:*** While the low cost of voice-controlled wheelchairs is a significant advantage, there is a need to determine the long-term cost-effectiveness of these devices, including maintenance and repair costs.
- **Technical challenges*:*** There are technical challenges involved in developing and implementing voice-controlled wheelchair systems, including issues related to speech recognition accuracy, noise interference, and system reliability. Further research is needed to address these technical challenges and improve the performance of voice-controlled wheelchairs.

The low-cost voice-controlled wheelchair is a novel development that aims to enhance the mobility of person with disabilities who may have little upper body strength or control. The use of voice commands for controlling the wheelchair is a novel idea that can provide greater independence and freedom of movement for wheelchair users. This technology can enable wheelchair users to control the chair's movements by simply using their voice, which can be especially helpful for those who have limited or no use of their hands or arms. Additionally, the use of affordable materials and components makes this wheelchair accessible to people who may not have the financial resources to purchase expensive, high-tech mobility devices.

3. Methodology

The methodology for developing a low-cost voice-controlled wheelchair would involve several steps, including:

3.1 Requirement Analysis: The first step in developing a low-cost voice-controlled wheelchair would involve understanding the requirements of wheelchair users, such as the types of movements they need to control, the range of motion needed, and the type of voice commands that would be most useful.

The types of movements that a disabled person needs to control a wheelchair can vary depending on the individual's physical abilities and the environment they are navigating. However, some of the typical movements that a wheelchair user needs to control include:

- **Forward and backward movement*:*** Wheelchair users need to be able to move their wheelchair forward and backward to navigate through spaces.
- **Turning*:*** Turning the wheelchair is also essential to navigate through narrow spaces or make sharp turns.
- **Speed control*:*** Wheelchair users need to be able to control the speed of the wheelchair, especially when navigating through crowded or busy areas.
- **Stopping and starting*:*** Being able to stop and start the wheelchair is critical to avoid collisions and maintain control.

- **Ascending and Descending Inclines*:*** Wheelchair users often need to navigate inclines, ramps, and uneven terrain, which requires the ability to control the wheelchair's movement in a way that is safe and stable.
- **Vertical and horizontal movement of seat*:*** In some cases, a disabled person may need to adjust the height or angle of the seat to accommodate different tasks or activities.
- **Control of additional features*:*** Depending on the design of the wheelchair, a disabled person may also need to control additional features, such as lights or other electronic devices, to enhance their mobility and independence.

The range of motion needed for a disabled person to control a wheelchair can vary depending on the individual's physical abilities and the type of wheelchair they are using. However, some of the typical ranges of motion needed to control a wheelchair include:

- **Arm and hand movements*:*** For people who have sufficient upper body strength and control, the range of motion needed to control a wheelchair may include arm and hand movements such as pushing or pulling the wheelchair's rims, pressing buttons or switches, and manipulating a joystick or other control interface.
- **Head and neck movements*:*** For people who have limited or no use of their arms and hands, controlling a wheelchair may involve using head and neck movements to operate switches or sensors, such as a sip-and-puff device or a headrest-mounted joystick.
- **Voice commands*:*** In the case of a voice-controlled wheelchair, the range of motion required would be minimal as the user would only need to use their voice to control the wheelchair's movements.
- **Foot and leg movements*:*** For some people, controlling a wheelchair may involve using foot and leg movements to operate foot pedals, knee levers, or other specialized controls designed for people with lower body impairments.

So, the range of motion needed to control a wheelchair can vary depending on the individual's physical abilities and the type of wheelchair control system used. It is essential to design the wheelchair and its controls to be adaptable and flexible, allowing for a range of control options that can be tailored to the user's specific needs and abilities.
The types of voice commands needed for a disabled person to control a wheelchair can vary depending on the specific design of the voice control system and the individual's needs and abilities. However, some of the typical voice commands that may be used to control a wheelchair include:

i. **Directional commands**: Voice commands such as "forward," "backward," "left," and "right" can be used to control the direction of the wheelchair.
ii. **Speed commands**: Commands such as "slow down," "speed up," and "stop" can be used to adjust the speed of the wheelchair.
iii. **Turn commands**: Commands such as "turn left" or "turn right" can be used to control the wheelchair's turning angle.
iv. **Distance commands**: Commands such as "move forward 5 feet" or "move backward 2 feet" can be used to specify the distance the wheelchair should travel.
v. **Emergency stop command**: A voice command to immediately stop the wheelchair in case of an emergency.
vi. **Other auxiliary commands**: Depending on the design of the wheelchair and the voice control system, additional voice commands may be needed to control auxiliary features such as lights, indicators, or other electronic devices.

So, the type of voice commands needed to control a wheelchair would depend on the specific design of the voice control system and the individual's needs and abilities. It is important to design the voice control system to be flexible and adaptable, allowing users to customize their commands based on their preferences and capabilities.

3.2 Component Selection: The next step would be to identify the appropriate components needed to build the wheelchair, including motors, controllers, microphones, and software for speech recognition.

Building an affordable voice-controlled wheelchair requires careful selection of appropriate components that meet the specific requirements of the design. Here are some of the key components needed to build an affordable voice-controlled wheelchair:

1. **Microcontroller*:*** A microcontroller is the brain of the wheelchair and is responsible for processing the voice commands and controlling the motors that drive the wheels. Popular microcontrollers for wheelchair applications include the Arduino, Raspberry Pi, and BeagleBone Black.
2. **Motor drivers*:*** Motor drivers are electronic circuits that control the speed and direction of the motors that drive the wheels. A variety of motor drivers are available, including H-bridge and PWM-based drivers.
3. **Motors and wheels**: The motors and wheels are responsible for propelling the wheelchair and allowing it to move in different directions. The type of motors and wheels needed will depend on the weight and size of the wheelchair.

4. **Battery:** A battery is required to power the wheelchair and its electronics. The battery should be selected based on the power requirements of the motors and the duration of use.
5. **Voice recognition module**: A voice recognition module is needed to process the voice commands and convert them into electrical signals that can be understood by the microcontroller. Some popular voice recognition modules include the EasyVR and the Voice Recognition V3 module.
6. **Sensors*:*** Sensors are needed to detect obstacles and avoid collisions. Infrared, ultrasonic, and laser range finders are commonly used for this purpose.
7. **Control interface**: A control interface is needed to allow the user to interact with the wheelchair using voice commands. This could be a microphone or a headset with a built-in microphone.
8. **Frame and chassis*:*** The frame and chassis of the wheelchair provide the structure and support for the various components. These should be designed to be lightweight, durable, and easy to assemble.

Therefore, building an affordable voice-controlled wheelchair requires careful selection of appropriate components that meet the specific requirements of the design. The components must be selected based on factors such as cost, reliability, performance, and ease of use.

3.3 Prototyping: Once the components have been selected, a prototype of the wheelchair would be developed to test the system's feasibility and functionality. This would involve integrating the components and software to create a working system that can be controlled by voice commands.

3.3.1 System overview

Fig. 1 below depicts the affordable voice control wheelchair's general architecture. The primary computer processor that serve as a conduit between the input and the output. The Raspberry Pi will receive voice orders, which will be recognized by a Smartphone application, and it will execute them. The Raspberry Pi will respond to the command by turning on the relevant motor, allowing the wheelchair to move forward, backward, left, right, or stop as shown in Fig. 2. Moreover, an infrared sensor is used to detect the obstruction that is 4 feet away from the wheelchair. The wheelchair moves in accordance with the initial order if the obstacle distance is greater than 4 feet. If not, the wheelchair will come to a stop. When the user gives the instruction “stop”, the ultrasonic sensor will stop operating. This is the project's safety function to protect users from running into obstacles. Last but not least, the buzzer is used to inform users that a command has been successfully executed by the system.

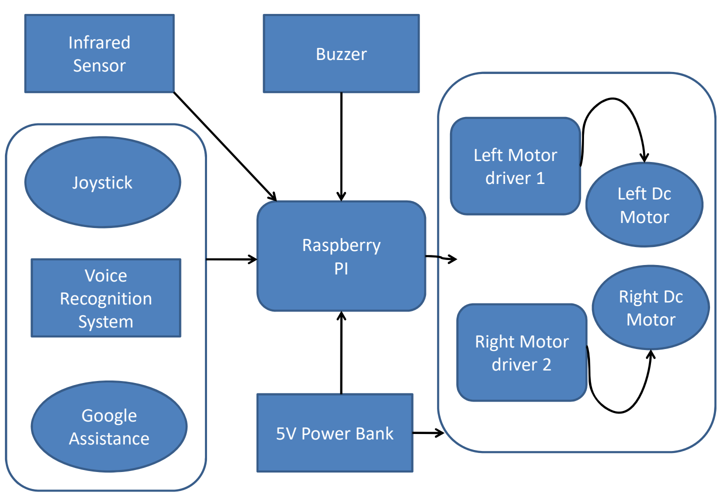

Fig. 1. General architecture of the propose voice activated wheelchair

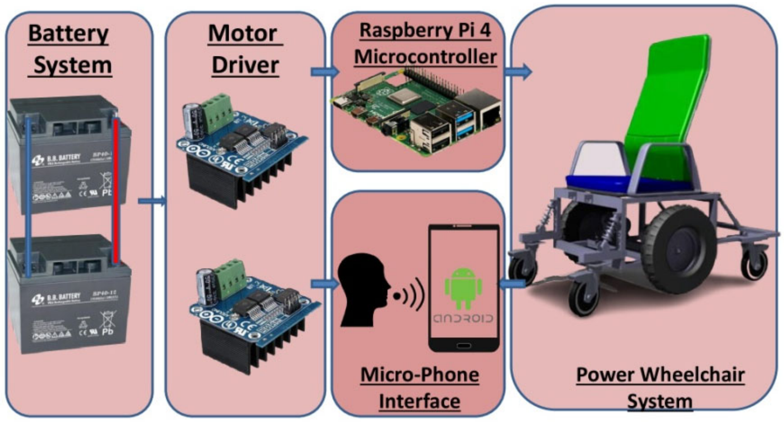

Fig. 2. Framework for overall voice activated System

3.3.2 Main controller of the system

The Raspberry Pi is a credit card-sized single-board computer that is capable of running a full operating system and can perform many of the same functions as a traditional desktop or laptop computer as shown in figure 3. It is powered by a CPU that typically ranges from 700MHz to 1.5GHz, and it usually comes with 512 MB to 8 GB of RAM, depending on the model. In addition to the USB ports, Ethernet, WIFI, and audio output you mentioned, the Raspberry Pi also has a variety of other ports and interfaces, including HDMI for display, a camera port, and a GPIO (General Purpose Input/Output) header that allows it to connect to various sensors and other devices.

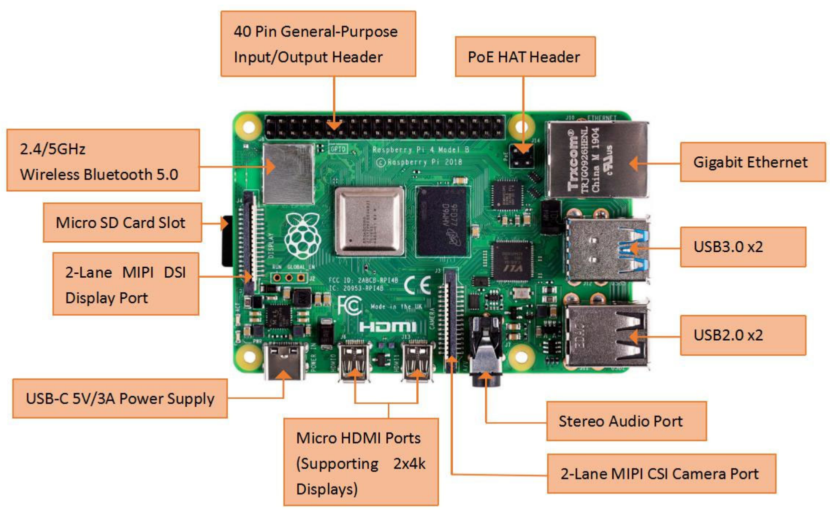

Fig. 3. Raspberry PI description

In this research, the Raspberry Pi 4 B Model is being used to perform several functions, including executing the output from a speech recognition system and obstacle detection. The speech recognition system being used is the Google API, which is one of several platforms that can be used for this purpose. In addition to its software capabilities, the Raspberry Pi is also being used to communicate with external hardware devices via its GPIO pins. Specifically, the GPIO pins are being used to connect to an infrared sensor and an H-Bridge, which are likely being used for obstacle detection purposes. The GPIO pins allow for two-way communication between the Raspberry Pi and the external devices, which enables the system to receive data from the sensors and control the H-Bridge as needed.

3.3.3 Controller of the proposed System

The system's voice recognition component is taken care of by Figure 4. When the user gives a verbal command (such as “forward”, “reverse”, “left”, “right”, or “stop”) to the Google Assistant, the instruction is forwarded to IFTTT (If This, Then That). IFTTT is a platform that allows for the integration of various services to create solutions in the realm of IoT (Internet of Things). From IFTTT, the command is then passed on to Webhooks. Webhooks is a platform that can translate the spoken instruction stored in the Google Assistant into a HTTPS protocol request. When an action is triggered in Webhooks, it can call back the Hypertext Transfer Protocol (HTTP) to initiate a response in the system. Overall, the purpose of this block is to convert the user's verbal command into a format that can be interpreted and executed by the Raspberry Pi.

The HTTPS protocol request that is generated by Webhooks is directed to the Blynk cloud's internet protocol (IP) address. The Blynk cloud is a cloud-based service that is designed to be fast, lightweight, secure, and scalable. It is capable of managing requests from IFTTT and can interpret them appropriately.

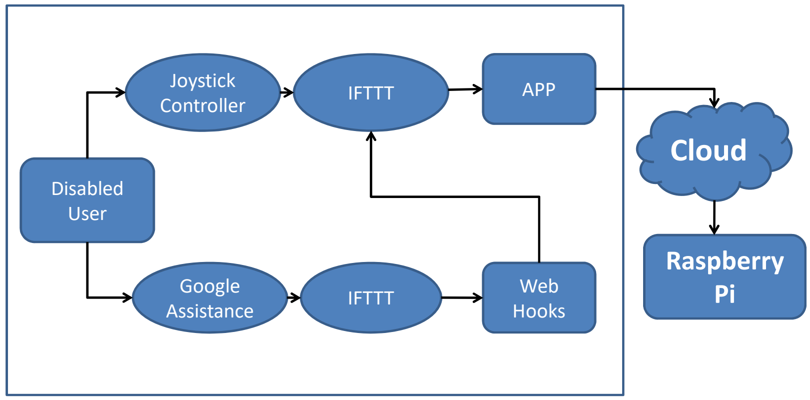

Fig. 4. Block diagram of Controller of the proposed System

In addition to its cloud-based services, the Blynk platform also supports running servers in various environments, including dedicated business environments and locally as open source software. This allows for flexibility in deploying and managing the system, depending on the needs and preferences of the user.

3.3.4 Safety Feature of the proposed system

The system's obstacle detection component is handled by Fig. 5. The IR sensor works by emitting a beam of IR radiation and then detecting the reflected radiation when it encounters an object. The detected signal is then fed back to the Raspberry Pi, which can interpret it and take appropriate action. The working principle of the IR sensor is known as triangulation, which involves using the angle of reflection of the IR radiation to determine the distance to the object. This principle is illustrated in Figure 5. So, the purpose is to detect obstacles in the path of the vehicle and alert the Raspberry Pi, which can then take appropriate action to avoid a collision or other hazards.

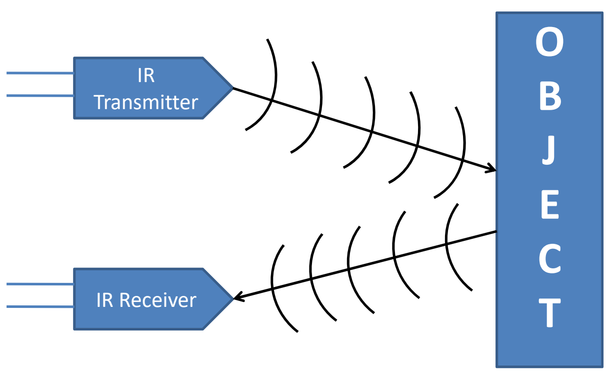

Fig. 5. IR sensor's operation

In this project, the infrared sensor is being used as a sensor for measuring distance. By measuring the amount of time it takes for the IR radiation to reflect back to the sensor, the Raspberry Pi can determine the distance to the object. This information can then be used to help the vehicle navigate and avoid obstacles in its path.

3.3.5 Visible output of the system

Fig. 1 shows the visual output of the system. The motor driver, the motor, and the buzzer are the three parts of this. Depending on the input the Raspberry Pi receives, each of these parts performs a particular purpose. The Raspberry Pi's GPIO pins cannot accept a direct connection from the motor, which is required to steer the car. The motor driver (H-Bridge) serves as a conduit between the Raspberry Pi and the motor as a result. By adjusting the motors' speed and direction, the motor driver is also utilized to control how the vehicle moves. The buzzer is then utilized to inform the user that their command has been successfully executed. This is crucial so that the user may be certain that the car is reacting to their orders and take the necessary action.

3.3.5.1 Motor Driver (H-bridge)

It seems that the BTS7960 43A H-Bridge High-Power Motor Driver Module is an important component of the system, as it allows for the control of DC motors to operate in any direction. The motor driver has a maximum current rating of 43A continuously with a voltage range of 6-27 volts and a maximum frequency of 25 KHz.

To connect the H Bridge motor driver to the Raspberry Pi GPIO, an opto-coupler circuit is used as protection for the Raspberry Pi as shown in figure 6. This is important because it ensures that any electrical spikes or other issues with the motor driver do not damage the Raspberry Pi. The opto-coupler circuit acts as a buffer between the motor driver and the Raspberry Pi, providing isolation and protection.

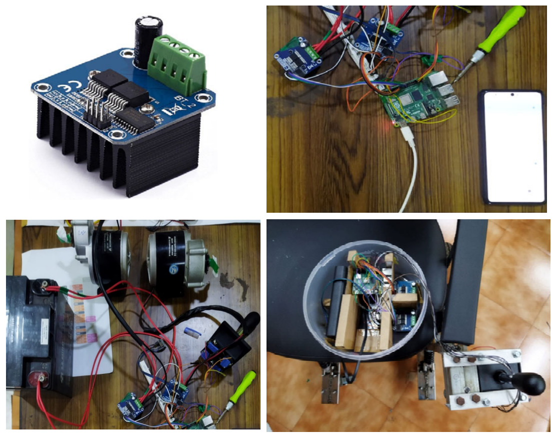

Fig. 6. Motor driver connection with Raspberry Pi and DC Motor

Two enable pins (Pin 1 and Pin 9) on the H Bridge motor driver can be used to connect the motor. Both of these pins must be put to a high condition in order for the motor to function. A low setting on one of these pins will cease the flow of electricity to the motor, effectively rendering it inoperable. This makes it possible to manage and halt the motor as necessary.

3.3.5.2 Geared DC motors

Two geared DC motors are used to control the direction of the wheelchair. These motors are mounted on the left and right sides of the mid drive wheel as shown in Fig. 7. Each motor can handle a maximum weight of 80-90 kg, which is suitable for the prototype development of the project.

The output of the motor is 324 rpm, which indicates how fast the motor can rotate under normal conditions. The input voltage range is 12-24 volts, which means that the motor can operate within this range. Additionally, the rated current is 19.2 Amp, which represents the current that the motor draws when it is working.

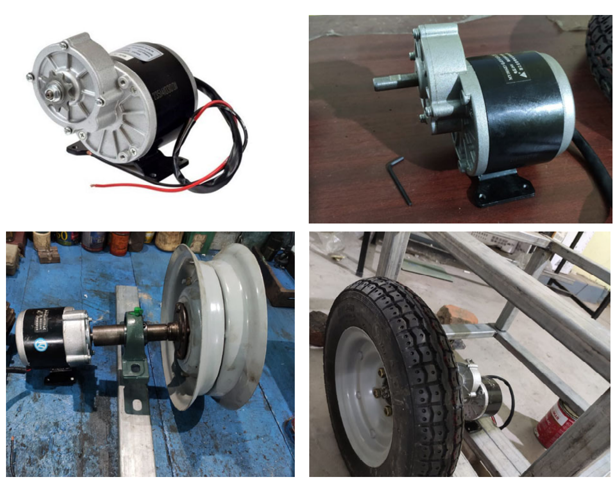

Fig. 7. DC Motor assembly with mid drive chassis

3.4 Testing: The prototype is tested under various conditions to ensure that the system is reliable, accurate, and safe for use. This testing involve both technical tests, such as measuring the accuracy of speech recognition, as well as user testing to evaluate the system's usability and user experience. This section concentrates on the various experiments that were carried out during the voice-activated wheelchair's development. The trial features an inquiry of the system's precision and responsiveness to user commands in both controller and voice command modes of control. The attribute of each system is then highlighted by comparison between the planned research and other pertinent research. This part also includes a presentation of the completed prototype.

3.4.1 Accuracy and the responsiveness of proposed system

The wheelchair's response time and adherence to user commands are used to gauge a system's accuracy. To assess the response of the voice activated wheelchair, many tests were therefore carried out.

Table 1
Average Time for 50 Trials Vs the Directional instructions

Sl.No.	Directional commands	Voice Response(Sec)	Joystick Response (Sec)
1	Forward	1.132	0.432
2	Backward	1.145	0.545
3	Left	1.125	0.455
4	Right	1.165	0.656
5	Slow Down	1.160	0.432
6	Speed Up	1.175	0.456
7	Stop	1.112	0.415
10	Move Forward 5 Feet	2.124	0.965
11	Move Backward 2 Feet	1.925	0.785

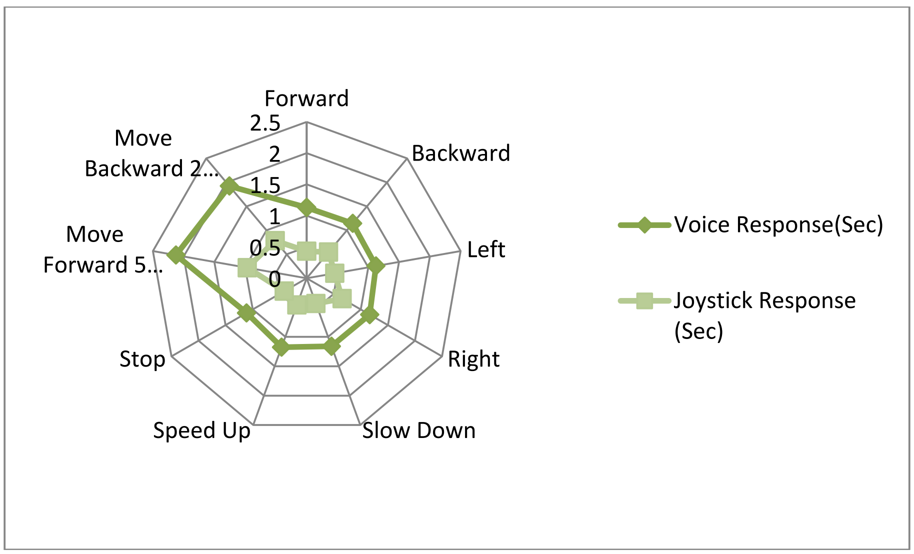

Fig. 8. Directional instruction time of voice activated vs. joystick control system

The amount of time the wheelchair needs to respond to commands in each control mode is shown in Table 1. The system is put through its paces 50 times in various directions, and the average testing duration is calculated. The speech recognition option has been found to respond to commands more slowly than the joystick controller. Nevertheless, the voice recognition mode can be regarded as a trustworthy system because the typical time needed is less than 1.2 seconds. Additionally, Figure 8's measurement demonstrates the great level of precision in the data.

Comparatively speaking, Table 2 and Fig. 9 illustrate the proportion of successful commands for each control method. 50 various directions are tried out with the system, and the wheelchair's responses to the commands are recorded. The measurement shows a slight difference between joystick controller performance and speech recognition mode performance. The joystick controller offers increased precision because the transmitter and receiver can directly communicate. A joystick controller's performance is also unaffected by the environment, including noise and other elements.

Table 2
Percentage of the Instructions that Effectively Completed 50 Trials

Sl.No.	Directional commands	Voice Response(Sec)	Joystick Response (Sec)
1	Forward	95	99
2	Backward	95	95
3	Left	97	100
4	Right	95	99
5	Slow Down	90	95
6	Speed Up	95	98
7	Stop	99	100
8	Move Forward 5 Feet	95	100
9	Move Backward 2 Feet	95	95

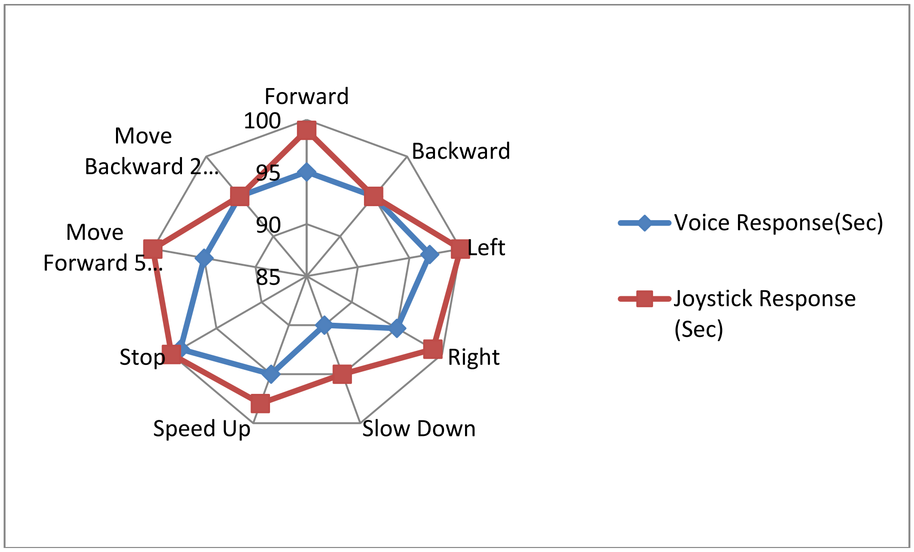

Fig. 9. Percentage of Effectively Completed 50 Trials of voice activated vs. joystick control system

Table 3 summarizes how each motor responded to the user's commands for each direction. When the user says “Go forward”, both motors will start moving forward. When receiving the signal “Stop”, both motors responded appropriately, bringing them to a static position. In response to the instruction “Move right”, the right motor will move backwards while the left motor advances the wheelchair. Using the same method as “Move Right”, but with each motor's condition altered, is the "Move Left" command. This time, the right motor will go forward while the left motor moves backward.

The wheelchair will therefore turn to the left. In addition, when the infrared sensor detects an obstruction in the wheelchair's route, the motors will promptly shut off. The wheelchair doesn't move until the obstruction is eliminated or a fresh order is given.

3.5 Cost Analysis: The final step in developing a low-cost voice-controlled wheelchair would be to optimize the cost of the system. This would involve identifying opportunities to reduce the cost of components, streamlining the manufacturing process, and exploring alternative sources of funding to make the wheelchair affordable for people who need it. The table below displays the anticipated cost of this design. The majority of the devices used in this proposed design are readily available in India's normal electronics market as well as markets around the world and internet retailers.

Table 3
Status of the user's motors, their direction commands, and the system output

Sl. No.	Directional commands	State of the left motor	State of the Right motor	System Output
1	Forward	Clockwise forward	Clockwise forward	Forward Move
2	Backward	Anticlockwise backward	Anticlockwise backward	Backward Move
3	Left	Anticlockwise backward	Clockwise forward	Turn Left
4	Right	Clockwise forward	Anticlockwise backward	Turn Right
5	Stop	No Motion	No Motion	System Stop

Table 4
The proposed voice activated wheelchair system's cost analysis

Sl. No.	Component Name	Component Quantity	Price Per Unit	Total Cost in Rupees
1	Chassis	1	12000.00	12000.00
2	Dc Motor	2	3500.00	7000.00
3	Raspberry Pi	1	5200.00	5200.00
4	Motor Driver	2	800.00	1600.00
5	Battery	2	2400.00	4800.00
6	Joystick Module	1	2200.00	2200.00
7	Voice Module	1	3500.00	3500.00
8	Smart Phone	1	4000.00	4000.00
9	Accelerometer	1	350.00	350.00
10	IR Sensor	4	200.00	800.00
11	Auxiliary items	1	1500.00	1500.00
	Total			42950.00

Table 5
Comparison between Voice Activated Vs. Joystick Controlled Wheelchair Using Raspberry Pi

Sl. No.	Description	Voice Activated	Joystick Controlled
1	Microcontroller	Raspberry Pi	Raspberry Pi
2	Type of Control System	Voice response	Joystick response
3	Type of Motor Used	DC Motor	DC Motor
4	Safety	Yes	No
5	Cost	Moderately High	Moderate

3.6 Comparison of wheelchairs with joystick and voice control

A comparison is conducted between the suggested systems, a voice-activated wheelchair, and an affordable joystick-controlled wheelchair in order to highlight the features of each system, as shown in Table 5. According to the analysis, the proposed technology is moderately expensive than the wheelchair that is joystick-controlled. The suggested system, however, provides greater functionality, including this double controller and security monitoring by means of an IR sensor.

4. Results

The affordable low cost voice control wheelchair was successfully built and tested. The wheelchair was able to be controlled by voice commands, allowing users with limited mobility to operate the wheelchair independently. The finished prototype for the voice-activated affordable wheelchair system is depicted in Figure 10. The components used in the wheelchair design were cost-effective and readily available, making it an affordable option for individuals with limited financial resources.

Fig. 10. Proposed Voice-Activated Affordable Wheelchair Prototype

5. Discussion

By giving people with impairments a practical mobility option, the inexpensive low cost voice control wheelchair has the potential to enhance their quality of life. Voice control technology is becoming increasingly popular and has the potential to be integrated into other assistive devices, making them more accessible and user-friendly for individuals with disabilities. Further research and development of the technology is needed to make it more accurate and reliable in detecting voice commands and avoiding collisions with obstacles.

The design of the wheelchair should be customizable to meet the specific needs and abilities of the user, including adjustability for height and seating position. The affordability of the wheelchair could be further improved by exploring options for using recycled materials for the frame and chassis. An affordable low cost voice control wheelchair has the potential to be a game-changer for individuals with disabilities who are seeking a cost-effective mobility solution. Further research and development is needed to improve the accuracy and reliability of the technology, and to make the design more customizable and eco-friendly.

6. Conclusion

The development of an affordable low cost voice control wheelchair has the potential to revolutionize the mobility solutions for individuals with disabilities. This technology has the ability to provide a cost-effective, user-friendly, and independent means of mobility for those who have limited mobility due to physical disabilities. The success of this project and its potential to improve the quality of life for those with disabilities highlights the importance of investing in assistive technologies that are both accessible and affordable. The affordability of the wheelchair makes it more accessible to people from all walks of life, regardless of their financial resources. Further research and development are necessary to improve the technology's accuracy and reliability in detecting voice commands and avoiding collisions with obstacles. Additionally, the design of the wheelchair should be customizable to meet the specific needs and abilities of the user. Overall, the development of an affordable low cost voice control wheelchair represents a significant step forward in assistive technology and holds great potential for improving the independence and mobility of people with disabilities.

6.1 Practical implication

The practical implications of an affordable low cost voice control wheelchair are significant for individuals with disabilities, their caregivers, and society as a whole.

Firstly, the affordability of the technology would make it more accessible to people with limited financial resources. This would provide a cost-effective mobility solution for those who otherwise would not be able to afford a traditional electric wheelchair.

Secondly, the user-friendly nature of the technology would make it easier for people with disabilities to operate the wheelchair independently. This would provide them with a sense of empowerment and freedom to move around as they wish without having to rely on others for assistance.

Thirdly, the integration of voice control technology in the design of the wheelchair has the potential to improve the quality of life for individuals with disabilities by reducing their dependence on others. It can provide them with a greater level of autonomy and control over their mobility, which can help boost their confidence and self-esteem.

Finally, the development of an affordable low cost voice control wheelchair represents a significant advancement in assistive technology.

6.2 Limitations

Despite the potential benefits of an affordable low cost voice control wheelchair, there are several limitations to be considered, including:

- **Accuracy and reliability:** The accuracy and reliability of the voice control technology used in the wheelchair are critical factors for its success. Inaccurate voice recognition and control can lead to potential safety hazards, such as collisions with obstacles.
- **Customization:** The design of the wheelchair should be customizable to meet the specific needs and abilities of the user. However, customization could also increase the cost of production, which may impact the affordability of the wheelchair.
- **Accessibility**: While an affordable low cost voice control wheelchair may be more accessible to individuals with limited financial resources, it may still be inaccessible to those who do not have access to reliable voice recognition

technology or have limited mobility in their arms and hands, which would make it difficult for them to operate the wheelchair by voice commands.

- **Durability:** The affordability of the components used in the wheelchair's design may affect its durability and longevity. This could result in frequent repairs and maintenance, which could increase the cost of ownership in the long run.
- **User Training**: Users may need training and practice to effectively use the voice control technology and operate the wheelchair safely. Without proper training and guidance, users may experience difficulty or safety concerns while operating the wheelchair.

In conclusion, while the development of an affordable low cost voice control wheelchair has the potential to revolutionize mobility solutions for individuals with disabilities, it is important to address these limitations to ensure the safety and effectiveness of the technology.

6.3 Future Scope

The development of an affordable low cost voice control wheelchair opens up several possibilities for future research and development, including:

i. **Improved accuracy and reliability**: Future research could focus on improving the accuracy and reliability of the voice recognition technology used in the wheelchair. This would ensure that the user's commands are correctly interpreted, reducing the risk of collisions and accidents.
ii. **Integration of other technologies**: The integration of other technologies, such as sensors and artificial intelligence, could enhance the functionality of the wheelchair. For example, obstacle detection and avoidance sensors could be used to further improve safety and reduce accidents.
iii. **Customization**: The future scope could also focus on customizing the design of the wheelchair to meet the specific needs of the user, such as their physical abilities and lifestyle. This would enhance the user experience and ensure that the wheelchair is tailored to their needs.
iv. **Cost Reduction**: As technology advances and production costs decrease, the cost of the components used in the wheelchair's design is likely to decrease as well. Future research could focus on finding even more cost-effective alternatives, making the wheelchair even more affordable for individuals with disabilities.
v. **Accessibility**: Further research could focus on improving the accessibility of the voice control technology, making it easier for people with disabilities to operate the wheelchair independently. This could include the development of new and innovative voice control methods, such as facial recognition or eye-tracking technology.

Therefore, the development of an affordable low cost voice control wheelchair presents several opportunities for future research and development. These developments could further improve the functionality, safety, and accessibility of the technology, providing individuals with disabilities with greater independence and mobility.

Acknowledgment

We would like to express our deepest gratitude to all those who contributed to this research project. First and foremost, we thank the individuals with disabilities who generously gave their time and insights to provide feedback on the design and functionality of the wheelchair. We also thank our collaborators from IGIT, Sarang for their support and expertise in developing the wheelchair prototype. Finally, we would like to express our appreciation for the invaluable guidance and support provided by our research supervisor and colleagues throughout the project. Without their expertise and encouragement, this research would not have been possible.

Conflict of interest

The author(s) declare that there are no conflicts of interest to disclose.

References

Aktar, N., Jaharr, I., & Lala, B. (2019, February). Voice recognition based intelligent wheelchair and GPS tracking system. In *2019 International Conference on Electrical, Computer and Communication Engineering (ECCE)* (pp. 1-6). IEEE.

Alim, M. A., Setumin, S., Rosli, A. D., & Ani, A. I. C. (2021, April). Development of a Voice-controlled Intelligent Wheelchair System using Raspberry Pi. In *2021 IEEE 11th IEEE Symposium on Computer Applications & Industrial Electronics (ISCAIE)* (pp. 274-278). IEEE.

Alkhalid, F. F., & Oleiwi, B. K. (2019). Smart Autonomous Wheelchair Controlled by Voice Commands-Aided by Tracking System. *Iraqi Journal of Computers, Communication and Control & Systems Engineering*, *19*(1), 82-87.

Chen, W. Y., Jang, Y., Wang, J. D., Huang, W. N., Chang, C. C., Mao, H. F., & Wang, Y. H. (2011). Wheelchair-related accidents: relationship with wheelchair-using behavior in active community wheelchair users. *Archives of physical medicine and rehabilitation*, *92*(6), 892-898.

Choi, J. H., Chung, Y., & Oh, S. (2019). Motion control of joystick interfaced electric wheelchair for improvement of safety and riding comfort. *Mechatronics*, *59*, 104-114.

Chung, C. S., Wang, H., & Cooper, R. A. (2013). Functional assessment and performance evaluation for assistive robotic manipulators: Literature review. *The journal of spinal cord medicine*, *36*(4), 273-289.

Devi, M. A., Sharmila, R., & Saranya, V. (2014, January). Hybrid brain computer interface in wheelchair using voice recognition sensors. In *2014 International Conference on Computer Communication and Informatics* (pp. 1-5). IEEE.

Dicianno, B. E., Lieberman, J., Schmeler, M. R., Souza, A. E. S. P., Cooper, R., Lange, M., Liu, H & Jan, Y. K. (2015). Rehabilitation engineering and assistive technology society of North America's position on the application of tilt, recline, and elevating legrests for wheelchairs literature update. *Assistive Technology*, *27*(3), 193-198.

Frizziero, L., Liverani, A., Donnici, G., Papaleo, P., & Leon-Cardenas, C. (2021). Smart Cane Developed with DFSS, QFD, and SDE for the Visually Impaired. *Inventions*, *6*(3), 58.

Jafar, F., Fatima, S. F., Mushtaq, H. R., Khan, S., Rasheed, A., & Sadaf, M. (2019, August). Eye controlled wheelchair using transfer learning. In *2019 International Symposium on Recent Advances in Electrical Engineering (RAEE)* (Vol. 4, pp. 1-5). IEEE.

Jones, M. A., McEwen, I. R., & Neas, B. R. (2012). Effects of power wheelchairs on the development and function of young children with severe motor impairments. *Pediatric Physical Therapy*, *24*(2), 131-140.

Klebbe, R., Scherzinger, S., & Eicher, C. (2022). Assistive Robots for Patients With Amyotrophic Lateral Sclerosis: Exploratory Task-Based Evaluation Study With an Early-Stage Demonstrator. *JMIR Rehabilitation and Assistive Technologies*, *9*(3), e35304.

Krahn, G. L. (2011). WHO World Report on Disability: a review. *Disability and health journal*, *4*(3), 141-142.

Kumar, S., & Kumar, S. (2015). Design and development of head motion controlled wheelchair. *International Journal of Advances in Engineering & Technology*, *8*(5), 816.

Kumtepe, E. D., Başoğlu, A. N., Corbacioglu, E., Daim, T. U., & Shaygan, A. (2020). A smart mass customization design tool: a case study of a portable ramp for wheelchair users. *Health and Technology*, *10*, 723-737.

Lajeunesse, V., Vincent, C., Routhier, F., Careau, E., & Michaud, F. (2016). Exoskeletons' design and usefulness evidence according to a systematic review of lower limb exoskeletons used for functional mobility by people with spinal cord injury. *Disability and Rehabilitation: Assistive Technology*, *11*(7), 535-547.

Letaief, M., Rezzoug, N., & Gorce, P. (2021). Comparison between joystick-and gaze-controlled electric wheelchair during narrow doorway crossing: Feasibility study and movement analysis. *Assistive Technology*, *33*(1), 26-37.

Machangpa, J. W., & Chingtham, T. S. (2018). Head gesture controlled wheelchair for quadriplegic patients. *Procedia computer science*, *132*, 342-351.

Machangpa, J. W., & Chingtham, T. S. (2018). Head gesture controlled wheelchair for quadriplegic patients. *Procedia computer science*, *132*, 342-351.

Madona, P., Nisa, H. K., Wijaya, Y. P., & Akhyan, A. (2020, May). The Design Of Wheelchair Systems With Raspberry Pi 3-Based Joystick Analog And Voice Control. In *IOP Conference Series: Materials Science and Engineering* (Vol. 846, No. 1, p. 012032). IOP Publishing.

Mairami, F. F., Allotey, P., Warren, N., Mak, J. S., & Reidpath, D. D. (2018). Adaptive invention: independence and mobility through modifications. *Disability and Rehabilitation: Assistive Technology*, *13*(7), 658-664.

Noman, A. T., Khan, M. S., Islam, M. E., & Rashid, H. (2018, October). A New Design Approach for Gesture Controlled Smart Wheelchair Utilizing Microcontroller. In *2018 International Conference on Innovations in Science, Engineering and Technology (ICISET)* (pp. 64-68). IEEE.

Opoku, M. P., Swabey, K., Pullen, D., & Dowden, T. (2019). Poverty alleviation among persons with disabilities via United Nations' sustainable development goals in Ghana: Voices of stakeholders with disabilities. *Sustainable Development*, *27*(1), 175-182.

Pires, G., Nunes, U., & Castelo-Branco, M. (2012). Comparison of a row-column speller vs. a novel lateral single-character speller: Assessment of BCI for severe motor disabled patients. *Clinical Neurophysiology*, *123*(6), 1168-1181.

Prasad, S., Sakpal, D., Rakhe, P., & Rawool, S. (2017, May). Head-motion controlled wheelchair. In *2017 2nd IEEE International Conference on Recent Trends in Electronics, Information & Communication Technology (RTEICT)* (pp. 1636-1640). IEEE.

Renuka, K., Harini, R., Balaji, V., & Ashok, N. (2021, March). Raspberry Pi based Multi-optional Wireless Wheelchair Control and Gesture Recognized Home Assist System. In *IOP Conference Series: Materials Science and Engineering* (Vol. 1084, No. 1, p. 012071). IOP Publishing.

Sahoo, S. K., & Choudhury, B. B. (2021). A Fuzzy AHP Approach to Evaluate the Strategic Design Criteria of a Smart Robotic Powered Wheelchair Prototype. In *Intelligent Systems: Proceedings of ICMIB 2020* (pp. 451-464). Singapore: Springer Singapore.

Sahoo, S. K., & Goswami, S. S. (2024). Theoretical framework for assessing the economic and environmental impact of water pollution: A detailed study on sustainable development of India. *Journal of Future Sustainability, 4(1)*, 23-34

Sahoo, S., & Choudhury, B. (2022). Optimal selection of an electric power wheelchair using an integrated COPRAS and EDAS approach based on Entropy weighting technique. *Decision Science Letters*, *11*(1), 21-34.

Škraba, A., Stojanović, R., Zupan, A., Koložvari, A., & Kofjač, D. (2015). Speech-controlled cloud-based wheelchair platform for disabled persons. *Microprocessors and Microsystems*, *39*(8), 819-828.

Tawil, Y., & Hafez, A. A. (2022, September). Deep Learning Obstacle Detection and Avoidance for Powered Wheelchair. In *2022 Innovations in Intelligent Systems and Applications Conference (ASYU)* (pp. 1-6). IEEE.

Thirugnanasambandam, K., RS, R., Loganathan, J., Dumka, A., & V, D. (2021). Optimal path planning for intelligent automated wheelchair using DDSRPSO. *International Journal of Pervasive Computing and Communications*, *17*(1), 109-120.

Upender, P., & Vardhini, P. H. (2020, November). A hand gesture based wheelchair for physically handicapped person with emergency alert system. In *2020 International Conference on Recent Trends on Electronics, Information, Communication & Technology (RTEICT)* (pp. 232-236). IEEE.
Upender, P., & Vardhini, P. H. (2020, November). A hand gesture based wheelchair for physically handicapped person with emergency alert system. In *2020 International Conference on Recent Trends on Electronics, Information, Communication & Technology (RTEICT)* (pp. 232-236). IEEE.
Wołoszyn, N., Grzegorczyk, J., Wiśniowska-Szurlej, A., Kilian, J., & Kwolek, A. (2020). Psychophysical health factors and its correlations in elderly wheelchair users who live in nursing homes. *International Journal of Environmental Research and Public Health*, *17*(5), 1706.

Yashoda, H. G. M. T., Piumal, A. M. S., Polgahapitiya, P. G. S. P., Mubeen, M. M. M., Muthugala, M. A. V. J., & Jayasekara, A. G. B. P. (2018, May). Design and development of a smart wheelchair with multiple control interfaces. In *2018 Moratuwa Engineering Research Conference (MERCon)* (pp. 324-329). IEEE.

Yenugula, M., Sahoo, S, K., & Goswami, S. S. (2024). Cloud computing for sustainable development: An analysis of environmental, economic and social benefits. *Journal of future sustainability, 4*(1), 45-60.