CHAIRLIDAR: LIDAR-BASED VOICE-CONTROLLED WHEELCHAIR WITH INDOOR AUTO-NAVIGATION SYSTEM USING SLAM ALGORITHM FOR QUADRIPLEGIC PATIENTS

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ABSTRACT

The study aimed to innovate an assistive device for persons who suffer from limb impairments and cannot control their wheelchairs manually, as the standard wheelchairs in the market are manually and joystick-controlled, which require hand movement to operate. The LiDAR-based voice-controlled wheelchair uses the Simultaneous Localization and Mapping (SLAM) algorithm and packages in Robot Operating System to navigate an indoor area through voice commands. A Light Detection and Ranging (LiDAR) sensor was used to scan and generate a 2D map of the surroundings and help navigate the wheelchair to its destination while avoiding obstacles. The user can control the wheelchair through basic voice and destination commands that automatically create paths to the desired location in a mapped indoor area. Additional ultrasonic sensors accommodated the detection of obstacles that the LiDAR cannot scan. The actual testing showed promising results for the basic voice commands feature. A total of 120 trials were conducted in an actual environment using basic commands, with a success rate of 51.67%, 43.33%, 50.83%, 62.50%, and 29.17% for forward, backward, left, right, and stop, respectively. On the other hand, the auto-navigation feature obtained an accuracy of 72.50% for room one and 57.50% for room two based from the total of 40 trials conducted. Overall, the testing showed the potential of a design that is more accessible and user-friendly for individuals with physical disabilities.

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Team WheelKins

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Chapter 1

THE PROBLEM AND ITS SETTING

1.1. Introduction

Mobility encompasses an individual’s ability to move their body within an environment, as well as the ability to manipulate objects. Disabilities and impaired body functions can hinder one’s ability to perform any mobility tasks and capability of independence. Over 1 billion people – about 15% of the global population – currently experience disability [1] - and this percentage rises as the global population increases. Disabilities can develop gradually, as occurs in polio and multiple sclerosis. Furthermore, disabilities can occur suddenly, as seen in traumatic spinal cord injury (quadriplegic), cerebral vascular accidents, and limb amputations. Aside from different disabilities and impairments, other causes may hinder one’s capability to move. For instance, the pain that is associated with knee osteoarthritis for elderly can have a considerable impact on their walking ability.

Statistics show that a wheelchair is needed by around 131,800,000 people, which is about 1.85% of the world's population [2]. According to the 2010 Census of Population and Housing, 1.44 million people, or 1.57 percent of the 92.1 million household population in the Philippines, were disabled [3]. As many years have passed, the population in the Philippines is growing, along with the number of people with disabilities. The Pilipinas Wheelchair Foundation stated that about 5.8 million Filipinos have physical disabilities which require a wheelchair [4]. Some devices can improve mobility regardless of which disability and body structure is impaired. Wheelchairs, walking aids, and prosthetic limbs are examples of these devices that provide widespread benefits. However, among those mentioned devices, wheelchairs are the most widely used for people with disabilities. In the Philippines, numerous types of wheelchairs are available, including manual wheelchairs, heavy-duty wheelchairs, electric wheelchairs, and many more [5]. However, most of those wheelchairs were either manually controlled or electric-powered, which is operated by a joystick.

The manual-controlled wheelchair needs muscular strength or someone who can assist the user in moving the wheelchair around, whereas the joystick-controlled wheelchair requires hand movements to move the wheelchair. Therefore, using these interfaces will be challenging for people with both upper and lower limb impairments, as well as the elderly, since their wrists are prone to become weak. In this paper, a voice-controlled wheelchair, incorporated with LiDAR technology for the auto mapping system, has the potential to recognize the difficulties of people with disabilities and impaired body functions and provide it with effective ways to alleviate the impact of their limitations.

1.2. Background of the Study

Modern technologies are getting involved in the healthcare sector, wherein developments in medical equipment and assistive devices are created. Smart healthcare, in which the devices have the intelligence to perform a particular task such as health monitoring, has emerged as the new technologies are utilized to bring a better experience for the patients and healthcare personnel. Aside from health monitoring devices, wheelchairs are also becoming intelligent-based to provide independent mobility for wheelchair users, especially quadriplegic patients. Recent studies about automated wheelchairs utilized sensorial media or sensors to make autonomous mobility possible for wheelchair users [6].

In the late 20th century, a joystick-based wheelchair had already become apparent as researchers were drawn into conceptualizing the idea of an intelligent wheelchair. A study of a modernized joystick-controlled wheelchair used the intelligent touchscreen interface technology to replace the standard mechanical joystick in an automated wheelchair [7]. The user only moves his finger on the touchscreen to control the movement of the wheelchair. An artificial neural network was used, containing an input layer of two nodes which are the finger coordinates on the touch interface joystick, and an output layer that distinguishes the corrected coordinates. A neural network algorithm reduced the error between the collected data and the reference data. The training of the neural network was executed through the reduction of the mean square error between the reference data and acquired results. The Feed-Forward algorithm was used by the models to adjust the nodes' weighting in different layers. Furthermore, enhanced speed and movement stability were ensured by using the neural network even if there is an impression of the wrong direction of the finger on the touchscreen interface and a reduction in speed due to the user's pathological condition. Overall, this paper noted that the users have more ease in using intelligent joysticks in wheelchairs than mechanical joysticks due to less muscular effort.

Over time, automated wheelchairs are further improved by applying up-to-date technology trends such as wearable technology. A study of a gyroscope-based wheelchair control system that uses a head-mounted wearable device aimed to have hands-free control over the wheelchair [8]. It implemented an electroencephalogram instrument – EMOTIV Insight headset, in a human-computer interface for recognizing and obtaining the user's head gesture signals. The head motion or head tilt of the user serves as the direction command to maneuver the wheelchair. The system has the EMOTIV Insight headset brain-based gyroscope that detects the head gesture of the user, a DC motor driver for the wheelchair's control in speed and directions, a microcontroller, and a laptop. The data obtained using EMOTIV and a personal computer will be transferred to the microcontroller (Arduino Uno), which will process the acquired data. These data are also used for the speed and direction instructions' management and control. The DC motor driver will control the motor in the wheelchair and maneuver this electric-powered wheelchair based on the user's command or head tilts – up, down, left, or right. This study showed that the proposed wearable technology-based control system for an electric-powered wheelchair has an acceptable significant average response time of almost 2 seconds and good results in command accuracy, sensitivity, and specificity, which acquired 99%, 99.16%, and 98.33%, respectively.

Nowadays, voice-recognition technology is commonly incorporated in smart devices, which provides convenience to the users. Recent studies in improving the standard manual wheelchair have also used voice-based technology to maneuver the wheelchair for independent mobility of wheelchair users. One of these recent studies about wheelchairs that have a voice-recognition system had developed an android mobile phone application based on Flutter software and Network-in-Network (NIN) structure approach which is Convolutional Neural Network (CNN)-based that is integrated with voice-recognition model for training and classifying the five voice-commands in the system – yes(forward), no(backward), left, right, and stop [9]. The android mobile application connects to the microcontroller through an offline Wi-Fi network hotspot. The developed mobile application will recognize the user's voice command that serves as the input, then transfers the output or the converted voice command to the Raspberry Pi microcontroller, which prompts the actuators to move the wheelchair based on the received voice command. Although the results in this study showed a high accuracy of voice-recognition commands and wheelchair maneuverability, an algorithm for speaker identification, which could give a safer mobile experience for the user, is not implemented in the voice-recognition model of the system.

Another study of voice-controlled wheelchairs has an obstacle detection feature [10]. The ultrasonic sensors in the system detect the nearby obstacle present in the operating environment by emitting a short ultrasonic pulse or an ultrasonic wave and receiving the reflected echo from that nearby object. The time taken of the emitted ultrasonic wave to reach the object and returning to the sensor measures the distance between the wheelchair and the detected obstacle. These sensors are placed at the front and rear of the wheelchair. When an obstacle is detected, motors in the wheelchair will be stopped from moving. In contrast to the other study of voice recognition-based wheelchairs, no mobile application was used or developed in this study. Only a microphone connected to a voice module was utilized for receiving the voice commands of the user. The voice module contains a voice recognition module that records the voice command given by the user and a voice capture module responsible for recognizing the voice commands by comparing the user's voice command to the voice command in the program of the system. The result of this study shows that the distance measurement of the ultrasonic sensor has a 4% error percentage. Despite having an error, the voice-controlled wheelchair with an ultrasonic sensor for obstacle-detection feature still provides safe mobility for wheelchair users.

LIDAR, also known as Light Detection and Ranging, uses laser light impulses that reflect with an object; with this, the distance is calculated according to time which is measured when mapping. LIDAR is generally used for scanning in various areas, such as in the fields of automotive and navigation of mobile autonomous robots. In this study, the proposed system integrates a combination of LIDAR for laser scanning [11]. LIDAR contributes a great advantage in this study because it is used for navigation and more accurate direction of the wheelchair. Instead of using only basic directions such as front, rear, and side, LIDAR can move the wheelchair to its desired location at ease and with increased reliability because of its capability to detect in real-time the dynamic obstacles, minimizing the risk of collisions in the wheelchair's pathway. Though having LIDAR is advantageous for the capabilities it can offer, one of the disadvantages commonly pointed out in projects using LIDAR is its contribution to the cost of the system.

Various types of electric wheelchairs have been introduced in the research industry since the early 1980s and are continually advancing worldwide [12]. Another type is the SLAM-based autonomous wheelchair navigation system. SLAM, also known as Simultaneous Localization and Mapping, is an algorithm that allows devices/robots to construct adjacent areas into a map while localizing their location on the map in real-time. LiDAR-based SLAM algorithms are usually a combined system for a more accurate navigation system of the wheelchair. These algorithms are able to utilize the use of laser scanners to obtain data to combine with the results from odometry localization. After obtaining the said data, the localization of the wheelchair and the static map are constructed. SLAM algorithm provides flexibility to the application of the navigation capabilities for the wheelchair. The SLAM algorithm incorporated with LiDAR gains the capability to use laser scanners for the mapping and localization algorithms. The map constructed is previewed like a 2D occupancy grid of data. The SLAM test focused on the validation of the map construction and localization of the wheelchair to collect the data on the navigation system. It was performed at different starting points to correct every error position to match the newly generated map. To construct a more precise mapping, it is generally proposed to perform a lot of processing, especially for the localization of indoor wheelchairs. There is also the capacity of the processor and the speed of the wheelchairs to be considered in proposing an automated indoor wheelchair.

1.3. Research Gap

There are already multiple academic studies that incorporate voice control and obstacle avoidance in wheelchairs. However, none of these projects have combined all these features in one. It is essential for patients with upper and lower disabilities, especially those patients who suffer from poliomyelitis, multiple sclerosis (MS), elderly people who are unable to move their wheelchairs on their own, and patients with spinal cord injury, to be able to navigate their homes or anywhere safely and conveniently. Therefore, the researchers have proposed implementing a voice-controlled wheelchair integrated with an auto-mapping and obstacle avoidance system in one set-up. Although the challenge for the study is considering different parameters such as the weight of the patient and the speed of the wheelchair, the proposed project will be able to help the target users control their wheelchairs independently and navigate with ease.

1.4. Research Objectives

To develop an automated wheelchair incorporated with LiDAR sensors that will analyze and collect data points to generate a map that will be used in auto-navigation to allow limb-impaired patients to move around without assistance from other people.

In particular, it aims to:

1. To modify a commercially available wheelchair through the integration of various sensors, modules, and microcontrollers for control and automation.
2. To develop an auto-navigation feature for indoor routing by utilizing the Simultaneous Localization and Mapping algorithm and LiDAR technology.
3. To develop a voice-controlled system by utilizing microcontroller and microprocessor.
4. To perform user acceptance testing and actual field test of the developed project prototype.

1.5. Significance of the Study

An automated wheelchair with a LiDAR sensor is important for people with both upper and lower limb disabilities because this mobility device will allow them to move around independently. This research is also beneficial for people who have difficulty moving their limbs due to other diseases or injuries. An ordinary wheelchair and other types of electric wheelchairs are only suitable for people with lower-limb impairments as they require hand movement to control the wheels, remote, or joysticks of the wheelchair. In this study, a patient can move from one place to another on a particular map through voice commands. Moreover, this research includes an obstacle detection and avoidance system that will help patients automatically avoid any detected obstacles along the pathway.

The proposed study has a social impact in which it can improve the quality of life of quadriplegic patients. This research helps people with limb impairments to have freedom of movement just like the rest of society. In addition, this can increase their sense of independence as they do not need other people to move the wheelchair for them. Moreover, this research has an economic impact in which the proponents have designed a voice-controlled wheelchair that is more affordable for most limb-impaired patients than any automated wheelchair available on the market.

The automated wheelchair for limb-impaired patients belongs to the research priorities for hospital equipment and biomedical devices under the Section II of Harmonized National Research and Development Agenda (HNRDA) of the Department of Science and Technology (DOST) since this research aims to create an assistive device designed for persons with disabilities. Additionally, this research mainly addresses the third goal of the Sustainable Development Goals (SDGs) of the United Nations, which is about good health and well-being to ensure healthy lives and to promote well-being for people. This study will improve the healthcare as well as the quality of life of persons with disabilities (PWDs), by incorporating various technologies to create an automated wheelchair.

The study will provide knowledge and understanding regarding the integration of technologies used in auto-navigation into mobile devices like wheelchairs. With the help of this research, advancements with automated wheelchairs may develop by incorporating various technologies to improve the mobility of limb-impaired patients.

1.6. Scope and Limitations

This research study aims to innovate an assistive device prior to persons who suffer from limb impairments, polio, multiple sclerosis, spinal cord injury, and the persons who cannot control their wheelchair manually, especially the older people. Voice recognition will be implemented in the wheelchair, where the system will recognize the patient's voice for the wheelchair to move but the system does not yet have the capability to recognize only one specific voice, thus it can recognize voices with similar tone with the user. In this study, only the English language will be used. LiDAR sensor will also be implemented for indoor auto-navigation and detecting static obstacles along the pathway. In addition, the researchers will focus only on implementing the device indoors and on one (1) floor to create a fixed map that will be used in the system.

This research study will not extend to the advanced features of an automated wheelchair with the use of LiDAR sensor, such as outdoor mapping, multi mapping via auto-navigation, compatibility of non-flat surfaces, patient status notification, and an alternative control in the wheelchair, as it requires a long period of time to learn and study. Moreover, the requirements of other components are beyond the financial capabilities of the researchers.

1.7. Definition of Terms

Light Detection and Ranging (LiDAR) - uses light in the form of a pulsed laser to measure distances from different surfaces. The light creates accurate information about the Earth's surface in three-dimensional form [13].

Simultaneous Localization and Mapping (SLAM) - is an algorithm or method used to localize the device and even build a map of the unknown environment [14].

Quadriplegic - one affected with partial or complete paralysis of both the arms and legs, especially as a result of spinal cord injury or disease in the region of the neck [15].

Voice/Speaker recognition - is the program's capability to recognize the voice of a speaker based on his/her distinct voiceprint [16].

Auto-navigation – refers to the capability of a system or device to navigate autonomously to arrive at a desired location within the mapped indoor area.

Chapter 2

REVIEW OF RELATED LITERATURE

2.1. Automated Wheelchair

2.1.1. Automated Wheelchair through Brain Control

For persons with disabilities, a wheelchair is essential since it can give them hope in life as they have limited physical movement. As technology keeps emerging, the solution for wheelchair users incorporated with the latest technology will also increase. As stated in the study of Masood et al. [17], a wheelchair controlled by brain signals is suitable for persons who experience neuromuscular disorders such as cerebral palsy and spinal cord injury, as they have problems with nerves and muscular movements. Researchers developed a brain control interface (BCI) that aims to connect humans and computers. The BCI's role is to directly translate brain activity into a sequence of control commands. It is a non-invasive procedure; hence, instruments will not be introduced into the body. This study uses the designed BCI system that will directly get the person's neural activity and let the system control the movement of the wheelchair, depending on the neural activity gathered from the brain signals. The BCI's primary function is to restore the motor functions of the persons who experienced neuromuscular disorders. The acquired data from the wheelchair part consisting of the EEG signal is connected via Bluetooth. Moreover, the data gathered was transferred to the controller part. In the controller part, the signal obtained from the brain has equivalent movement commands. In addition to brain control, a two-organization Obstacle Detection

Based on a Quick Striking Impediment Recognition Calculation is included. In this process, data and tests were run to identify the obstacles.

Another study regarding brain-controlled wheelchairs was also conducted specifically for disabled persons who are paralyzed. In the past, many automated wheelchairs were designed for disabled persons to have control with physical devices; hence, the weakness of those previously innovated wheelchairs was that they required physical strength or muscular movements — paralyzed patients would not be beneficiaries of those kinds of wheelchairs. Mohammad et al. [18] designed a project study in which the interpreted brain signals of the paralyzed users will control the wheelchair to move. Similar to the previous study, the concept and technology were closely the same; the control will depend on the user's imagination. Eye blink detection is essential to control the wheelchair. The Neurosky MindWave Mobile 2 was used to record brain signals, which records and analyzes various sorts of brain activity. This BCI-designed wheelchair has two operating modes: automatic control and subject control. If the user wishes to activate the automatic control, the intelligent system incorporated in the wheelchair will take care of obstacle avoidance using the ultrasonic sensor embedded in the wheelchair. On the other hand, if the patient's mental state is not in the condition, a joystick subject control was also designed to control the wheelchair manually. The difference of this study is it has an option to control the wheelchair independently; It was mentioned in the study that a specific range of blink strength is also measured for the safety of the user and the prevention of unintentional movements. The project was fully functional, using a brain signal to control the wheelchair, and their target patient would be the best users for this type of wheelchair. Improvements and other features are possible as long as they help the user feel comfortable and free to move.

Table 2.1: Review of Related Literature in Automated Wheelchair through Brain Control

Author/s	**Year**	**Title of the Paper**	**Relevant Findings**	**Relationship to the Study**
K. M. Amaan Masood, Anuraag Manvi	2020	Brain Operated Wheelchair Using a Single Electrode EEG Device and BCI	This study predominantly introduces the use of a simplistic uni-polar device to obtain EEG for the development of a Brain-Computer Interface (BCI). It aims to provide a feasible solution to integrate a Brain-Computer Interface (BCI) with automated identification and avoidance of obstacles. The automated obstacle detection and avoidance system aims to provide a way to easily detect obstacles and easily correct the course.	Both studies aim to innovate an automated wheelchair
M. M. Khan, S. N. Safa, M. H. Ashik, M. Masud, and M. A. Alzain	2021	Research and Development of a Brain-Controlled Wheelchair for Paralyzed Patients	This study presents a brain-controlled wheelchair model to assist disabled and paralyzed patients. The wheelchair is controlled by interpreting Electroencephalogram	

			(EEG) signals, also known as brain waves. The use of this brain-controlled wheelchair can improve the quality of life of a paralyzed patient.	

2.1.2. Automated Wheelchair through Eye Directive

Emerging technologies such as automated wheelchairs through eye directives are designed specifically for those individuals who are unable to move their legs or hands. The main idea of the study conducted by the researchers is to generate a gesture sensing application through image detection of the eyes for the directive control of the wheelchair. This study used Raspberry Pi for the processing of the embedded system, which will control the connected output devices such as the DC motors. This microcontroller will manage the level of the speed and the direction of the wheelchair. The eye-detection was successfully made and it was able to control the two connected dc motors according to the direction of the processed data that the embedded system obtained. The research is still in the initial stages of development of the operating system with the hopes to conduct the detection of the iris by installing Matlab within it and the embedded system. The research also looks forward to future work to embed Linux programming to match the dc motors with the direction movement of the eyes [19].

Another study regarding Eye-Movement-Controlled Wheelchair was conducted but with the implementation of Kalman filtering and Wavelet Transform-Support Vector Machine (WT-SVM) algorithms. Electrooculograma

(EOG) was used because it can identify eye movement's conscious and subjective directions. Based on the previous studies conducted, other researchers used soft electrodes to measure EOG; hence, these electrodes are stiff and have poor biocompatibility, which may induce allergies or irritations when in direct contact with the skin. In this study, researchers used a flexible hydrogel biosensor, which has high deformability and excellent biocompatibility. The methodology of this study consists of three works: fabrication of a flexible hydrogel biosensor, signal classification, and manipulating a wheelchair. The biosensor is in charge of gathering EOG and strain readings from the wheelchair user. Signals will be input into the computer digitally after being processed by the peripheral circuit. Using the classification technique, different eye movement states can be determined. The pc eventually creates instructions to drive stepper motors, which subsequently control the wheelchair. The biosensor used in this study gains a higher rate of 96.3% eye movement recognition accuracy than the traditional rigid system, which had 91.9% accuracy [20].

Table 2.2: Review of Related Literature in Automated Wheelchair through Eye Directive

Author/s	Year	Title of the Paper	Relevant Findings	Relationship to the Study
J. K. Desai and L. McLauchlan	2017	Controlling a Wheelchair by Gesture Movements and Wearable Technology	This study used Raspberry Pi for the processing of the embedded system, to which will control the connected output devices such as the DC motors. This microcontroller will	Both studies aim to innovate an automated wheelchair

			manage the level of the speed and the direction of the wheelchair.	
X. Wang, Y. Xiao, F. Deng, Y. Chen, and H. Zhang	2021	Eye-Movement-Controlled Wheelchair Based on Flexible Hydrogel Biosensor and WT-SVM	This study presents an eye-movement-controlled wheelchair prototype based on a flexible hydrogel biosensor and Wavelet Transform-Support Vector Machine (WT-SVM) algorithm.	

2.1.3. Automated Wheelchair through Head Movements

Science and technology are constantly evolving, and human living standards are being raised by smart technologies. With the advancement of technology, a significant amount of research studies on wheelchairs have been implemented. Various methods have been used in research works in the field of automation. Automated wheelchairs through head gestures are one of the studies that have been developed by many researchers to help a physically disabled person move independently. P. Dey et al. conducted a study to develop a smart wheelchair that can be navigated using different head gestures. The project includes unique features that make the mobility of the wheelchair user more comfortable and convenient [21]. The wheelchair was moved in five different directions based on different head gestures using an accelerometer sensor. The wheelchair's direction is controlled by Arduino UNO, which uses Relay as a motor driver. The wheelchair is powered by a solar panel, emphasizing the use of green energy, and LDR has been used as a light detection sensor to assist the user in moving when there is insufficient light. To provide secure and safe movement, a seat belt sensor was used as a switch, and an ultrasonic sensor was used as an obstacle detector. The researchers observed several improvements that are to be addressed in other future works, including the new advancements such as voice recognition autonomous system, Bluetooth module connection, and WIFI module in a wheelchair. As concluded, the entire system's operation has been observed, and commendable results have been obtained to make the smart wheelchair efficient and effective for the user.

Another study was conducted by H. Patil on designing a wheelchair tilt communicator system that can operate a wheelchair of a handicapped person who has suffered a spinal cord injury and is unable to move their hands or legs using head tilt movements [22]. The design and development of the head motion-controlled wheelchair was achieved with the utilization of tilt sensors and wireless modules. Tilt sensors were used to provide the wheelchair’s directions which are forward, backward, left, and right based on the head movements of the user. Consequently, the wheelchair stops when the head of the user is in a normal position. The tilt sensors are linked to a potential divider circuit, which generates the necessary voltage signals. These signals are fed into a diode logic circuit, which converts them into the desired signals needed to move the wheelchair's motors in the proper directions. These signals are then transmitted wirelessly to the wheelchair by a wireless transmitter attached to the top of the hat itself. At the receiver end, a wireless receiver will receive these signals, decode them, and drive a ULN2003 amplifier. The ULN2003 integrated circuit drives the SPDT relays in the receiver section, which controls the motors. The wheelchair is propelled by DC geared motors. The researchers have tested the project in various cases, and the results show that the wheelchair is working successfully, along with the remote with tilt sensors, for all conditions. The completion of the project study proves that the head motion-controlled wheelchair is an effective solution for patients who have suffered a spinal cord injury and cannot move their hands and legs to manipulate a manual or automatic wheelchair, as concluded.

A study in line with MEMS technology was also conducted to address the problem of quadriplegic users. People with quadriplegia refer to paralysis affecting the trunk, legs, and arms from the neck down. Several studies about automated wheelchairs were invented, but some users still experience the pain and discomfort in controlling those wheelchairs. In this study, researchers implemented the MEMS technology in automated wheelchairs specifically for users who cannot control their upper and lower limbs. MEMS is a tiny fabrication method that combines mechanical components, sensors, actuators, and physical science on a standard SI substrate. In this study, the MEMS technology is an accelerometer that provides a signal based on the change in acceleration due to gravity analysis. A cap would be placed on the top of the head of the user and will sense the tilt movement of the head. The tilt movement of the head's user will be the basis of the control system to control the automated wheelchair. When the head tilts in a forward direction, the wheelchair moves in a forward direction; if the head tilts in a backward direction, the wheelchair moves in a backward direction; if the head tilts in the left, the wheelchair moves left; and if tilts in the right, the wheelchair moves right. Signals acquired from the device will be converted into digital signals using the microcontroller, which will now give a signal to the dc motor to move [23].

G. Marins et al. conducted a study that presents a cost-effective solution for people with disabilities in their legs and arms. The goal of the study is to use an Inertial Measurement Unit (IMU) to acquire head movements and use these movements to move an electric wheelchair [24]. The researchers used a sensor GY-87, an IMU with an accelerometer, gyroscope, and magnetometer, to develop the prototype, with all measurements in three-dimensional axes (x, y, and z). The sensor was attached to a headphone, with the plane xy on top of the user's head and the x-axis pointing forward. For data extraction and processing, an Arduino UNO microcontroller was used to acquire data from the GY-87 sensor through the I2C protocol. Moreover, MatLab runs a pattern detection algorithm for classifier training, which can then be embedded in the microcontroller to drive a motorized wheelchair directly. For data classification, Euclidean distance, Mahalanobis distance, and an artificial neural network were used; hence, the researchers provided an alternative to wheelchair users with greater limitations while minimizing development costs. As concluded, a method of possible implementation was developed, and more possible innovations were highlighted. The researchers indicate a more advanced control design for the developed system, in which speeds can take continuous values within a range. Furthermore, a laser scan around the chair can create a shared control that will prevent collisions and improve the accuracy of the maneuvers.

Table 2.3: Review of Related Literature in Automated Wheelchair through Head Movements

Author/s	Year	Title of the Paper	Relevant Findings	Relationship to the Study
P. Dey, M. M. Hasan, S. Mostofa and A. I. Rana	2019	Smart wheelchair integrating head gesture navigation	The main ambition of this study is to introduce a smart wheelchair which will be navigated with different head gestures of the user. Accelerometer sensor has been used to move the wheelchair in five different directions according to different head gestures	
H. Patil	2020	Design and Making of Head Motion Controlled Wheelchair	The aim of this study is to design a wheelchair tilt communicator system that could operate the wheelchair of the handicapped person with the help of tilt of head movements.	Both studies aim to innovate an automated wheelchair
D. K. S. K Risheek Anand, C Sai Kumar	2021	MEMS Operated Automatic Wheelchair	The study developed a wheelchair for physically disabled folks that use head motion and MEMS sensing element interfaced with DC motor. MEMS sensing element could be a small electronic mechanical sensing element that effectively translated head movements into laptop taken signals.	

			The measuring instrument information is graduated for motion recognition.	
G. Marins, D. Carvalho, A. Marcato, and I. Junior	2017	Development of a control system for electric wheelchairs based on head movements	This study used an IMU (Inertial Measurement Unit) to capture movements from the user's head and, through this movement be able to move an electric wheelchair.	

2.1.4. Automated Wheelchair through Joysticks

The automated wheelchair significantly expands the capabilities of traditionally powered devices. These technologies are most useful, especially to physically impaired persons, because they no longer require the assistance of another person. The innovation of an automated wheelchair controlled by a gesture joystick would significantly help the PWDs and elders to move freely and comfortably without stressing themselves. This automated wheelchair has three (3) main functions — joystick control, ultrasonic sensor, and gesture control. The joystick is mainly the manual control of the system in which the user will issue the direction. The ultrasonic sensor is responsible for identifying obstacles to avoid. Moreover, the gesture control that works with MEMS technology as an accelerometer sensor is responsible for maintaining the acceleration whenever the wheelchair changes its direction. In order to make the programming of this project attainable, an ATmega2560 microcontroller was used, which has 54 pins in total, out of which 16 are used for analog input pins, and the remaining pins are used for interface [25].

Another research study conducted by Kadirova and Nenov [26] aims to design an Arduino-based power wheelchair to ensure the safety of disabled or elderly people. The study utilized different sensors and devices, such as ultrasonic sensors, a LiDAR sensor, and the joystick. The researchers used two ultrasonic sensors that detect obstacles near the wheelchair user. However, ultrasonic sensors have difficulty identifying concave obstacles such as descending stairs, holes, curbstones, and flat obstructions on the ground because the inclined incidence of the beam is going to be reflected away. Therefore, the researchers also utilized LiDAR technology to ensure the safety of the wheelchair user. The LiDAR sensor uses light or laser to measure and scan the environment, producing a 2D map of the terrain and precise distance measurement. By incorporating two ultrasonic and LiDAR sensors into the wheelchair, the system can detect and prevent collisions with static and moving obstacles, such as a wall, a moving car, or a walking person. The researchers used a standard joystick so that the user could easily control the wheelchair in any direction within a 360-degree radius. Kadirova and Nenov [24] have observed that the PWM duty cycle was affected by how the joystick was pressed, which also determines the speed of the DC motors of the wheelchair. The researchers have stated that the expected speed of wheelchair movement is around 20km/h when the joystick is fully pressed. The sensors and joystick are connected to the Arduino board, which is a microcontroller that processes all of the data and commands. The data and commands will be delivered to the motor driving integrated circuit that will control the movement of the wheelchair. The microcontroller unit relies on the valid input signal coming from the sensors and joystick. The wheelchair will not move if the user does not press the joystick. On the other hand, if the user pushes the joystick forward, the power wheelchair will continue to move until the sensors detect an obstacle. However, if the user keeps pushing the joystick forward, the system will analyze the signals from ultrasonic and LiDAR sensors and decide where to turn to avoid the obstacle and return to the same track. Although the power wheelchair with various advantages has been developed, Kadirova and Nenov [26] have been noted to include a voice recognition system in future work. Furthermore, the neural-based algorithm can be applied to improve the control of the wheelchair.

Table 2.4: Review of Related Literature in Automated Wheelchair through Joysticks

Author/s	Year	Title of the Paper	Relevant Findings	Relationship to the Study
M. R. Sathuluri, S. Bathulla, A. Azeem, and Y. Pavan Kumar	2017	Gesture and Joystick Controlled Multipurpose Automated Wheelchair	The aim of the study is to explore the importance of advanced wheelchair which can substitute a better service for the physically challenged. The automated wheelchair has a creative design with an ultrasonic sensor and a joystick-controlled facility. It further includes a gesture-controlled system for the comfort of individuals.	Both studies aim to innovate an automated wheelchair

S. Y. Kadirova and T. R. Nenov	2020	Design of Power Wheelchair Controller	The research aims to design a power wheelchair based on the Arduino to ensure the safety of the disabled or elderly people. A standard joystick was used to allow the user to easily control the wheelchair in any direction. The research also incorporated the use of LiDAR technology and ultrasonic sensors to detect and avoid possible collisions with obstacles. If the sensors detect an obstacle in front of the user and the user keeps pushing the joystick forward, the movement of the wheelchair will depend on the sensors to avoid obstacles then it will return to the same track.	

2.1.5. Automated Wheelchair through Mobile Application

Nowadays, people tend to use their mobile devices instead of doing things manually because of the ease in accessibility it provides to every individual. The popularity of Android-based smartphones has led to the development of useful applications that can be installed on mobile devices. For persons with disabilities (PWD), an electric-powered wheelchair is the most suitable type of wheelchair because it reduces the assistance they need to control the wheelchair. It also provides high mobility, where users can move freely and easily. In a research study conducted by Srinivasan et al. [27], an automated wheelchair is controlled via smartphone with its corresponding mobile application. This study mainly consists of the sensory part and the Android application. The Android application offers a customizable interface in which PWDs can move the wheelchair in any direction (forward, backward, left, and right). Users are free to choose from controlling the wheelchair by voice, gesture, and keypad. When a user speaks a command, the internal microphone of the mobile device will receive the command and convert it using the speech recognition embedded in the Android phone. However, the speaker should be close enough to the device's microphone to have an accurate move. Aside from voice commands, users can also use the keypad or joystick to control the direction of the wheelchair. Similarly, the user can operate the wheelchair using MEMS (Micro-Electrical Mechanical Systems) technology. When the screen is tilted horizontally, the accelerometer detects the change in orientation and measures the acceleration speed. The wheelchair is moved following the acceleration. Aside from the said interfaces, users can customize controls based on the preference they want to use. A sensor is also attached to the wheelchair, where it can detect and avoid obstacles. As concluded, this research study expands the use of technology, in which people with disabilities and the elderly can make their life easier and independent from people.

Table 2.5: Review of Related Literature in Automated Wheelchair through Mobile Application

Author/s	Year	Title of the Paper	Relevant Findings	Relationship to the Study
S. Selvaraj, A. Ganasekar, P. S. Rani, and P. Ezhumalai	2019	Mobile Controlled Automated wheelchair for Disabilities	This project presents an android application which provides several options for controlling the movement of wheelchairs effectively. The application enables People with Disabilities (PWDs) to operate the wheelchair with minimum effort. Apart from voice commands, the application detects and measures the tilt change and moves the wheelchair based on the degree of the tilt. It also provides a soft joystick as in mobile games to ease the operation of the wheelchair.	Both studies aim to innovate an automated wheelchair

2.1.6. Automated Wheelchair through Voice Commands

Voice has always been an important means of communication between humans. Voice Recognition Systems have come a long way over the years, and the process has ensured its presence due to the well-established need for voice-operated systems. Mobility is one field that is not falling behind in terms of technological advancement. The main disadvantage of manual wheelchairs is their difficulty and reliance on others for mobility. Despite that fact, several studies were conducted to enhance the manual wheelchairs to become automated wheelchairs through voice commands by incorporating voice recognition systems to control the locomotion movements of the wheelchair.

A study about a voice-controlled wheelchair system was conducted by Malik et al. where the wheelchair is recommended to use a speech recognition module to control a wheelchair whenever possible. The goal of this project is to facilitate the movement of disabled or handicapped people, as well as elderlies who are unable to move well, to enable them to live a life with less reliance on others for their daily movement [28]. The project employs an Arduino kit (Atmega 328) and DC motors to control the movement of the wheelchair based on the user's voice. An android phone, incorporated with an android application, will be utilized as an intermediary to recognize the user's voice which will be the input of the system. There are five basic movements that can be applied to the user's wheelchair, and these are (1) Moving forward, (2) Moving backward, (3) Turning to the right, (4) Turning to the left, (5) Stop condition. Furthermore, Ultrasonic Sensors were utilized to detect obstacles in the path of the wheelchair. Moreover, a Bluetooth device will act as the main component to connect the wheelchair and android phone. The Bluetooth device secures the connectivity of the android phone and wheelchair to ensure that only one device is connected at a time. The study shows that the researchers were able to deploy the voice automated wheelchair; however, some errors occur based on the mispronounced words of the user. For instance, words like "right" were recognized as "write"; approximately 5% of errors occurred in this case. Consequently, the project was tested in a noisy environment, and it shows that as the noise increased, the recognizer found it difficult to recognize the user's voice and frequently took commands from what it heard in the noisy environment. For the future scope of the study, the wheelchair can only function properly if the weight of the load is less than 50 kilograms. Furthermore, the wheelchair may also include a gesture feature for the movement implementation of the wheelchair.

Another research study was conducted by Meena et al. in developing a voice-controlled wheelchair, which aims to improve the lives of disabled people, especially those with severe impairments, by increasing their mobility accessibility. However, aside from voice commands, the wheelchair can also be controlled by using a joystick [29]. This study used an HM2007 voice recognition module which corresponds to conduct speech processing. It is connected to the receiver (RX) pin of the Arduino to receive a stream of coded data from the module defining the various programmed direction commands. Moreover, the motors are connected to the relays and the L293D IC, which is then connected to the Arduino. The L293D is a typical motor driver or Motor Driver IC that allows DC motors to drive in either direction. It operates on the H-bridge concept. An H-bridge is a circuit that allows voltage to flow in either direction. This study successfully implemented a motorized wheelchair that could be controlled via voice recognition or joystick. The voice recognition worked for most of the commands, with over 95% success rate of the system recognizing the voice commands. The only reason that the system may fail to recognize the commands is when a word was not correctly vocalized.

With further enhancements, this study can increase its weightlifting capacity since the weight limit of the load for the system must be below 50 kilograms for the wheelchair to function properly. Furthermore, sensors for avoiding obstacles can be associated.

A research study conducted by M. Al Rakib et al. intends to establish a comparable wheelchair with intelligence that will assist people with disabilities in their mobility. With that being said, the researchers developed a voice-operated wheelchair designed to support themselves independently in terms of mobility. The wheelchair will be operated by voice commands using a phone application, which will serve as the input of the system and the bridge between the Bluetooth module and the Arduino. The system will receive spoken commands from the unilateral mic, which will be positioned according to the user's convenience, and the HC05 Bluetooth module will recognize the speech. All of the user's desired directives will be addressed by the Arduino Mega, in which instructions for each direction are written in the form of a program. The Arduino Mega is connected to motors, which enable the wheelchair to be driven anywhere. As concluded in the study, the benefits of this project are simple to control and use, no need for a medical specialist to operate it, low installation costs, and dependability in an emergency [30].

Raiyan et al. [31] conducted a study to create a design of a voice-controlled automated wheelchair using Arduino. The prototype includes a voice recognition system, obstacle detection system, and a GSM-based navigation system. The voice recognition system of the wheelchair allows the limb-impaired patients who have trouble using their hands to control the wheelchair through voice commands. The study utilized the EasyVR3 module to record, store, and train the voice commands in both English and Bengali, but it is also possible to train the device in any dialect and language. The voice recognition device processes the user's voice and detects if the voice command matches the previously trained data. The microcontroller used in the study is the Arduino Mega, which manages all the signals coming from the voice recognition device and other sensors. The Arduino Mega will transmit the data to the motor controller of the wheelchair if the voice command matches the trained data. The motor controller directs the wheelchair in its desired direction by controlling the movement of the motor. The study also includes an ultrasonic sonar sensor for the user's safety. The sensor allows the limb-impaired patients to avoid colliding with any detected obstacles present along its route. Furthermore, the design of the study incorporates the GSM module that is used in the navigation system to track and deliver messages to a close person or relative of the user in case of emergency. The study shows that the researchers developed an automated wheelchair design that incorporated a voice recognition module, a microcontroller, and a GSM module. In addition, obstacle avoidance technology allows the user to avoid possible accidents. The wheelchair can also carry an approximate 70 kg weighted person at a minimum speed of 3.5 km/h. Raiyan et al. [31] have noted several issues to be addressed in future research, including the noise reduction in speech processing to allow a wheelchair to operate smoothly in a noisy environment and placing the devices in the most appropriate position for good wheelchair balancing.

Advances in speech recognition technology have allowed people to control devices through voice commands. Other researchers have combined this technology with another device to create a machine or instrument that is more convenient for people. A study conducted by several researchers developed a voice-controlled wheelchair by incorporating voice recognition technology with a manual wheelchair to help people with both upper and lower limb disabilities. The voice-controlled wheelchair consists of a voice recognition module for wireless communication, a microcontroller, and a motor controller. The voice recognition module processes the user's voice and will send the signal to the microcontroller through the Bluetooth module if the voice command, such as the forward, backward, turn left, turn right, or stop, has been recognized. In addition, the study includes a motor drive to control the direction and speed of the DC brushed motor of the wheelchair, the hall effect sensors to detect the wheel rotation speed, and the infrared sensors for obstacle detection. A joystick was also added to the wheelchair as an additional feature. The wheelchair struggles to move from a complete stop when it is loaded with more than 65 kilograms, but this can be resolved by replacing or upgrading the motor of the wheelchair. The voice-controlled wheelchair has been developed successfully and has a high success rate in three different languages: English, Chinese, and Malay. With these results, the voice-controlled wheelchair can significantly improve the lives of people with upper and lower limb disabilities [32].

From finding and analyzing what type of controllers are suited for patients that are quadriplegic, paralytic, or those who are unable to move their wheelchairs independently, such as the elderly, [33] implemented a wheelchair that incorporated two controllers. One controller is by using the voice to command the wheelchair to either go forward, backward, left, right, or stop. The voice can also be used to change the speed of the wheelchair or turning its lights on and off. Two modules are used in implementing this type of controller – the SpeakUp Click module (VR1) and Easy Voice Recognition module (VR2). By the use of Dynamic Time Warping (DTW) and Hidden Markov Model (HMM) algorithms, [33] was able to implement a speaker-dependent voice system wheelchair which is ideal in considering the safety of the patient. Furthermore, the commands “forward," "speed one,” and “speed two” were also used to increase the speed ratio of the wheelchair when using the head tilts controller. Head tilts controller is the other type of controller applied in the system. It incorporates more commands compared to the voice controller with the addition of forward-left and forward-right. Numerous tests had been made with different parameters while using this type of controller, and results showed a success rate for each command after training the wheelchair prior to the implementation. With the integration of BNO055, an altitude sensor, into the system and automatic calibrated program, the wheelchair can be accurately moved by head tilting in both outdoor and indoor settings. According to [33], the head tilts controller is the preferred mode to be used in navigating indoors among the two controllers. This is because the user has more control over the wheelchair through tilting and turning his head rather than having limited voice commands in controlling the wheelchair. Finally, both controllers work hand-in-hand in the successful operation of the wheelchair. The researchers showed that voice and head tilt controllers are helpful for quadriplegics and paralysis patients and elderlies.

Mobility is one of the main concerns regarding patients with disabilities. The usage of wheelchairs helped lessen the difficulty of mobility, and it was made more accessible to patients. With the advancement of technology over time, a lot of innovations were made, leading us to the invention of creating autonomous wheelchairs. A lot of Autonomous wheelchairs have different kinds of innovations. There are wheelchairs that have multiple input navigation, obstacle avoidance using sensors, embedded home automation systems, and wheelchairs with different ways of navigation, including head-controlled, mind-controlled, tongue-controlled, gesture-controlled, and the most commonly used type, voice-control navigation. Another study was conducted using smartphone-based wheelchair navigation and home automation for the disabled [34]. This wheelchair has lots of choices in navigation, almost taking care of a lot of concerns when it comes to the mobility of the wheelchair. This study's goal is to provide mobility assistance to the patient in order for them to acquire some physical independence. A disabled person lacks the capability of independent mobility at all times, and the proposal of autonomous wheelchairs, which are voice-controlled, offers them relaxation. The patients will just have to speak over their smartphones and give a voice command whenever they want to navigate their wheelchairs on their own. When the wheelchair is in autonomous mode, the user can give a voice command, and it will lead them to their desired destination. To aid the wheelchair in avoiding collisions, 4IR sensors have been developed for obstacle detection and to detect a drop on the surface.

These sensors will send the data from all four directions to the microcontroller. The microcontrollers then will process the data received and compare the values to the threshold value. If they obtain a value lower than the threshold value, it will relay the stop command to the motor driver. The Controller is designated to receive the data transmitted from the android phone. Once the android phone, connected via Bluetooth, has sent a voice command, the data will be compared with the saved commands and their values before relaying to the controller. This paper provided results that an autonomous wheelchair can serve its function even with different types of disabilities. Since android phones are commonly used nowadays, connecting and embedding the navigation system on their mobile devices could be one great advantage. It is recommended that the system and processors used would be affordable to serve its purpose and be much more accessible to more patients. It is also important to keep the system user-friendly and to avoid complexity. For future developments, a GPS module could be embedded in the system as well for tracking and outdoor navigation. Torch and door lock systems could also be added to the wheelchair through its driver circuit. Android phones could support additional features such as sending a message whenever the patient needs help or raising an alert alarm to notify the neighbor’s home. These additional features have minimal additional costs and would be a lot more help for the user.

Table 2.6: Review of Related Literature in Automated Wheelchair through Voice Commands

Author/s	Year	Title of the Paper	Relevant Findings	Relationship to the Study
M. Ilyas Malik, T. Bashir, M. Omar, and F. Khan	2017	Voice Controlled Wheelchair System	This project aims to control a wheelchair by using a speech recognition module which is designed to control a wheelchair using a voice of a person. Speech recognition technology is a key technology that will provide a new way of human interaction with machines or tools.	Both studies focus on developing a voice-controlled wheelchair and aim to innovate an automated wheelchair
K. Meena, S. Gupta, and V. Khare	2017	Voice Controlled Wheelchair	This study presents an automatic wheelchair using voice recognition. The powered wheelchair depends on motors for locomotion and voice recognition for command. The circuit comprises an Arduino, HM2007 Voice recognition module and Motors.	
M. A. Al Rakib, S. Uddin, M. M. Rahman, S. Chakraborty, and F. I. Abbas	2021	Smart Wheelchair with Voice Control for Physically Challenged People	This project intends to develop a comparable smart wheelchair that is controllable by voice instructions which makes the wheelchair intelligent and can	

			assist the user in his or her mobility task.	
Z. Raiyan, M. S. Nawaz, A. K. M. A. Adnan and M. H. Imam	2017	Design of an Arduino Based Voice-Controlled Automated Wheelchair	The study aims to create an Arduino-based voice-controlled wheelchair. The researchers were able to process the voice commands in both English and Bengali language in order to control the wheelchair. However, the researchers have noted to include a noise reduction feature for the wheelchair to operate smoothly even in a noisy environment.	
T. Kian Hou, Yagasena, and Chelladurai	2020	Arduino based voice controlled wheelchair	The purpose of the study is to develop a voice-controlled wheelchair by incorporating the voice recognition technology with a manual wheelchair for people with both upper and lower limb disabilities. The commands for three different languages, English, Chinese, and Malay, were tested 50 times resulting in a high success rate of voice command recognition from around 96% to 100%.	

M. F. Ruzaij, S. Neubert, N. Stoll, and K. Thurow	2017	Design and Implementation of Low-Cost Intelligent Wheelchair Controller for Quadriplegias and Paralysis Patient	A voice-controlled wheelchair is helpful for quadriplegic patients. However, further innovation must be done in order for it to work properly in an indoor environment.	
A. K. Dalsaniya and D. H. Gawali	2016	Smart Phone Based Wheelchair Navigation and Home Automation for Disabled	When the wheelchair is in autonomous mode, the user can give a voice command and it will lead them to their desired destination.	

2.2. Automatic Voice Recognition System for Automation and Control

Voice recognition systems have long been used in the field of technology in operating various machines that help in the day-to-day operations of humans. A study conducted by a series of researchers created a small robotic vehicle that is controlled by a voice. It is implemented with the use of an Arduino UNO, which contains the codes for the program, connected to a smartphone device through Bluetooth. The user gives the commands such as forward, backward, right, left, and stop through an Android application called AMR_VOICE, and these commands are then sent and interpreted by the Arduino board to tell the robotic vehicle what to do. The study about the “voice-controlled robotic vehicle” can be applied in various fields. These include applications in automated vehicles, difficult situations that require machine intervention, helping disabled people that require wheelchairs, military operations, etc. With further innovation and development, the project can provide promising results in the future [36].

A study compares three different implementations of voice-controlled wheelchairs. The goal of [36] is to analyze the advantages and disadvantages of each model and recommend a possible solution that limits the flaws and increases the advantages. In [37], the model mainly includes a voice recognition module (HM2007), PIC16F877A microcontroller, keypad, an LCD, and GT-311 ultrasonic sensor for obstacle avoidance. The microprocessor serves as the mind of the whole system. It receives and sends messages to the wheels according to the data received from the input of the voice recognition unit. The voice command given by the user can be seen as the output displayed from the LCD integrated in the wheelchair. Although the [37] model is implemented with voice control, the keypad is still incorporated to serve as another alternative for controlling the wheelchair. Overall, the project was successful even though it had minimal errors regarding voice control in a noisy environment. Studies [38] and [39] also created a wheelchair similar to [35] except with different microcontrollers, additional recognition modules, and added features such as Intelligent Home Navigation System (IHNS) implemented in [38]. In [36], a similar approach was proposed in creating a voice-controlled wheelchair. The significant difference is that instead of using PICs as a microcontroller, Raspberry Pi was proposed to be the main controller for future projects. Raspberry Pi increases the functionality of the microcontroller since it can store more data and operate faster, and it reduces the number of modules needed to be used due to the Application Programming Interface (API) available in its system. Moreover, the effectiveness of the voice control system is designed by working with APIs and creating intelligent algorithms. The utilization of gears is also proposed to counter the possible twitch in moving spontaneously and increase the power of the wheelchair. [36] was able to find alternative solutions that will help future research in voice-controlled wheelchairs implement a system that is economical and, at the same time, efficient.

Although voice-based technology is implemented in some automated wheelchair studies, the voice-recognition feature wherein recognizing a specific person's voice is rare in those existing works. One of the factors that errors happen in voice recognition is because of the presence of noise. However, existing algorithms used to remove the noise of a specific band deteriorate the audio signal. In a research study conducted by Bae et al. [40], the voice recognition method was developed using the Adaptive Mel-Frequency Cepstrum Coefficient (MFCC) and Deep Learning. MFCC uses Discrete Cosine Transform (DCT) to determine the Logarithm energy of the filter bank configured in consideration of human auditory characteristics. The suggested filter by the researchers aims to reduce data loss and impose the weighted value on the data area. The study proposed a noise removal filter that uses DFT or Discrete Fourier Transform, in which the higher frequency band of audio signal was extracted over a specified decibel. Moreover, the triangle band-pass filter was used in the filter bank which will eliminate the noise. The obtained cepstrum for voice recognition is being applied to the Deep Neural Network, resulting in an efficient and improved recognition rate and a speech recognizer that can be used in an embedded system that has a small memory capacity. In an Adaptive MFCC proposed by the researchers, the voice data was being converted to the Mel-scale algorithm that allows recognizing the voice even if the noise was being combined with the sound. The study was demonstrated using MATLAB to show the effectiveness of the proposed algorithm in an irregular noise environment. In the experiment, the researchers recorded and used different words that served as the voice signal. The voice signal was converted to Mel-scale, and the time domain was converted to a frequency domain based on the DFT. Using the Mel-scale filter bank, the noise was filtered out. Based on the findings of the researchers, the recognition rate of Adaptive MFCC is 96 ~98%, which is higher compared to the 96% recognition rate of existing MFCC. The study effectively minimized the noise and data loss without damaging the audio data. The researchers have also incorporated Deep Learning to be able to use voice recognition even without the DB. The researchers have noted that removing white noise in home appliances is already undergoing a more advanced adaptive filter.

Leu and Lin [41] utilized MFCC (Mel - Frequency Cepstral Coefficients) technique in a human auditory filtering model to extract voice features for a specific speaker. The Gaussian Mixture Model (GMM) was also used for the statistical model of the energy distribution of the human voice when developing the text-independent speaker identification system. Basically, GMM was used to design the feature model or acoustic model of the speaker. The process of MFCC composes of voice signal as the input, frame blocking for dividing the input signals into frames, window function for increasing the continuity of the signals in a frame, Fast Fourier transform for converting digital signals into spectral data, triangular bandpass filter (Mel scale) for simulating the spectral data of human auditory, and DCT (Discrete Cosine Transform) for quantification of spectral energy data into units of data. Integrating the MFCC (Mel-Frequency Cepstral Coefficients) technique with Gaussian Mixture Model (GMM) results in a higher accuracy of speaker identification than the system that only uses MFCC.

Table 2.7: Review of Related Literature in Automatic Voice Recognition System for Automation and Control

Author/s	Year	Title of the Paper	Relevant Findings	Relationship to the Study
M. Saravanan, B. Selvababu, A. Jayan, A. Anand, and A. Raj	2020	Arduino Based Voice Controlled Robot Vehicle	Voice control has a wide variety of applications and can be very useful when implemented in wheelchairs to help disabled people	Both studies focus on developing a voice-controlled vehicle
R. Chauhan, Y. Jain, H. Agarwal, and A. Patil	2016	Study of Implementation of Voice Controlled Wheelchair	Utilizing Raspberry Pi as the microprocessor of the system will help in storing more data, operate voice control faster, and eliminate the need for voice recognition modules in implementing a voice-controlled system.	Both studies aim to innovate a voice-controlled wheelchair
H. S. Bae, H. J. Lee, and S. G. Lee	2016	Voice Recognition Based on Adaptive MFCC and Deep Learning	The research proposed an Adaptive Mel-Frequency Cepstral Coefficients (MFCC) to produce a higher recognition rate than the existing MFCC. The voice data was converted to a Mel-scale algorithm in order to recognize the voice even if it is being combined with the noise. The study has also minimized the noise and data loss without damaging the audio data.	Both studies aim to implement a voice recognition system
F. Y. Leu and G. L. Lin	2017	An MFCC-based Speaker	Integrating the MFCC (Mel-Frequency Cepstral Coefficients)	

		Identification System	technique with Gaussian Mixture Model (GMM) results in a higher accuracy of speaker identification for voice recognition than the system that only uses MFCC.	

2.3. LiDAR Sensor for Obstacle Detection and Avoidance

A LiDAR sensor is an active sensor that emits a laser beam to illuminate its surroundings; this emitted laser beam will return to the sensor after reflecting on the surface and will be processed to measure the ranges precisely [42]. With this operation of a LiDAR sensor, it can serve as an obstacle-detection device for a moving vehicle. Mobile robots also use LiDAR sensors to test obstacle detection and avoidance algorithms. [43] proposed an algorithm for obstacle detection and obstacle avoidance system which utilized a 2D RPLiDAR on a mobile robot. The obstacle detection part of the algorithm has filtering, preprocessing, and clustering techniques to obtain information about the present obstacles. Moreover, the obstacle avoidance algorithm used a systematic approach wherein the angle from which the destination point is present, the distance of the obstacle with respect to the reference point, the destination point and size of the robot, and the angle from which the robot will turn are determined. LiDAR data was used by the Raspberry Pi to specify the coordinates where the mobile robot moves relative to the reference point or position. UART, a serial communication, is used as the communication interface between the LiDAR and raspberry pi. The result of this work proved that the method implemented in the proposed algorithm in obstacle detection had obtained the obstacle information, and the obtained LiDAR data were filtered, preprocessed, and clustered, which is vital in obstacle classification. The mobile robot has avoided the detected obstacle and reached its right destination. The overall designed algorithm, for this case, is only for static obstacles. Thus, a dynamic obstacle avoidance system for future work is recommended.

Aside from mobile robots where LiDARs are mounted for obstacle detection and avoidance features, Autonomous Ground Vehicles (AGVs) also use LiDARs that can provide safety in autonomous driving. Perumal et al. [44] proposed an intelligent obstacle avoidance system for Autonomous Ground Vehicle (AGV) using LiDAR and a novel neural network model – Feed Forward Neural Network for the avoidance system's intelligence. LiDAR sensors can provide hybrid-vision to AGVs as these sensors are reliable to operate in various conditions such as day, night, and fog. Thus, a LiDAR sensor – LiDAR Lite V3 – was used for obstacle detection. LiDAR data contains the distance of the obstacle and the angle from which the obstacle is detected. The study also presented the intelligent Field of View (FOV) mechanism which imitates human driving behavior. The orientation of the laser beams emitted by the LiDAR sensor is based on the proposed Field of View (FOV). For the obstacle avoidance system, the Feed Forward Neural Network is implemented to transform the collected LiDAR data from the FOV into an avoidance decision. This neural network has three layers – input layer, hidden layer, and an output layer which will allow it to conclude with the right decision based on the position of the detected obstacle. The output layer contains the output neurons; these neurons are the decisions such as the forward, left-turn, right-turn, backward, and stop, which will be delivered to the vehicle control system that is responsible for moving the wheels based on the decision. Results from this study show that the proposed lidar-based obstacle detection and avoidance feed forward neural network model for autonomous ground vehicles outdo the classical mathematical approaches such as the 2D collision cone approach. Also, the model takes less time for making the right avoidance decision, and the used algorithm is more capable of drifting the AGV from collision threats than the existing obstacle avoidance approaches that are based on classical mathematical approaches.

Baum et al. [45] utilized a LiDAR sensor, specifically a LiDAR Lite sensor, on a robotic wheelchair as an obstacle-detector. This study developed a negative obstacle detection algorithm that will be implemented on a robotic wheelchair. Negative obstacles are depressions on the ground surface, such as curb drop-offs and descending staircases. These types of obstacles pose a danger to wheelchair users since negative obstacles can only be perceived at a near distance which would be difficult to detect and avoid at a normal speed. Including a LiDAR sensor for detecting the said type of obstacle will increase the safety of wheelchair users. The developed real-time algorithm monitors time-varying changes in measured distances and works by assuming that the abrupt increase in the monitored value represents a detected approaching negative obstacle. There is a set threshold value based on the identified error of the LiDAR Lite's range measurement. If the time derivative of the measured range reached the threshold value, this implies that a negative obstacle is detected. Based on its findings, there were observed variations in the measured range values which differ from the expected range value; this can be explained by different causes of inaccuracy. The first one could be the different responses of the LiDAR sensor to the various types of surface materials. The non-ideal surfaces, including the dark or shiny surfaces, have increased the inconsistency in LiDAR's distance measurement readings. Kalman Filter is the recommended technique in the algorithm to mitigate the increase of variations in the distance measurements of the sensor. One more cause could be the observed beam divergence which causes a sigmoid pattern that likely affects the outcome of the algorithm. Furthermore, the result shows that the algorithm has a reliable performance in the detection of the controlled samples of negative obstacles. It acquired 90% accuracy for 8 cm impediment and above, and 76% accuracy for an obstacle with a depth of 6cm and above. These findings can be further improved by integrating multiple LiDAR sensors, installing two sensors at the front of the wheelchair and another two sensors at the back. An empirically derived linear regression was formulated which can be utilized to determine the necessary distance for the wheelchair to safely stop as a function of approach speed. Additionally, having more trials is advised to better understand the algorithm, and further characterize the sensor and the wheelchair. The first one should be an experiment wherein the effects of the characterized beam divergence on obstacle detection performance are evaluated. Second, an experiment assessing the performance of numerous LiDAR Lite sensors together should be conducted. Third, a trial for improving the minimum distance of the obstacle to be detected. Finally, the findings of the study can be applied, in time, to the navigation of a robotic wheelchair especially when negative obstacles are present in the environment.

Another study stated in [46], that a wheelchair is considered autonomous especially when it directs you to your desired destination without having to control it manually and without continuous guidance from other people. Although LiDAR is beneficial for obstacle detection, one disadvantage of it is that the laser can only scan when it is on a horizontal plane at the height above the user sitting on the wheelchair. LiDAR in this study is placed on a wooden plank above the head level of the user. This makes the obstacles below the height of the LiDAR unaccustomed to the map. Due to this reason, proximity sensors are added below the height of the LiDAR in order to detect the obstacles beneath it and include it in the map as well. The use of ultrasonic proximity sensors is unwarranted when used to detect large obstacles, but in the case of smaller obstacles, LiDAR sensors alone would not be able to account for the obstacle in the map which might cause collisions.

A different study indicates that LIDAR is generally used for scanning in various areas such as in the fields of automotive and navigation of mobile autonomous robots. In this study, the proposed system integrates a combination of LIDAR for laser scanning and Kinect for video acquisition [47]. LIDAR contributes a great advantage in this study for it is used for navigation and more accurate direction of the wheelchair. Instead of using only basic directions such as front, rear, and side, LIDAR can move the wheelchair to its desired location at ease and with increased reliability because of its capability to detect in real-time the dynamic obstacles, minimizing the risk of collisions in the wheelchair's pathway. From the results of this study, the images obtained from the LiDAR laser are the key points that will be used for the matchmaking algorithm. LiDAR with region growing stereo matchmaker increases the possibility of generating images without the loss of accuracy. LiDAR combined with Kinect solution with the use of Eye Gaze - Tobii system contributes to the information that detects the obstacles. The Entry and exit localization of the indoor map is determined as well. Provided with the results, the map was generated using the trajectory planning methods and provided an optimal route path that leads towards the end of the trajectory. In conclusion, the two systems (LiDAR and Kinect) complement each other, bringing out the best and removing the disadvantages of each other's system. Removing one of the systems increases the possibility of collision risks and the accuracy of the system performance. LIDAR is advantageous for the capabilities it can offer, one of the disadvantages that are commonly pointed out in projects using LIDAR is its contribution to the cost of the system.

Another study presented by Hutabarat et al. [48] developed an autonomous mobile robot incorporated with a LiDAR sensor for the obstacle avoidance system of the device. LiDAR sensor was used to avoid obstacles due to its multiple advantages including high precision with the long detection range, as compared with other conventional sensors that have limitations on detection distance, processing complexity, and spatial resolution. In the study, the researchers used the X4 YDLiDAR with a motor that can rotate to produce a 360-degree view and has an indoor distance range of 0.12 m to 10 m. The study used the Braitenberg vehicle strategy to maneuver the mobile robot movement. The type 2b of the Braitenberg vehicle method was applied in which the sensor on the left side was used to control the right motor of the mobile robot and vice versa. The data collected from the LiDAR sensor and other control algorithms used in the study were being applied on a Raspberry Pi 3 single computer board. The Raspberry Pi 3 processes and delivers the data to a motor driver, which controls the DC motor of the mobile robot. According to the findings of Hutabarat et. al. [48], the LiDAR sensor can detect distances from around 0.12 meters to 10.5 meters with an average error of 0.9 percent. Moreover, the mobile robot was able to avoid the colored objects, in which the measurement of the LiDAR sensor was not affected by the color of the object and the intensity of the ambient light. However, the mobile robot would not be able to avoid transparent objects, such as acrylic and polycarbonate bottles, because these objects do not reflect the laser emitted by the LiDAR sensor. The researchers were able to create an autonomous mobile robot incorporated with an obstacle avoidance system that can navigate an indoor room without colliding with colored objects or obstacles.

Table 2.8: Review of Related Literature in LiDAR Sensor for Obstacle Detection and Avoidance

Author/s	**Year**	**Title of the Paper**	**Relevant Findings**	**Relationship to the Study**
T. R. Madhavan and M. Adharsh	2019	Obstacle Detection and Obstacle Avoidance Algorithm based on 2-D RPLiDAR	Utilizing the 2D RPLiDAR sensor in the proposed algorithm enabled the mobile robot to reach its destination while having the capability of avoiding the present static obstacles.	Both studies incorporate LiDAR technology for Obstacle Detection and Avoidance System and Autonomous Mobility
P. S. Perumal, M. Sujasree, K. Siddhardha, and K. Gokul	2020	Lidar Based Intelligent Obstacle Avoidance System for Autonomous Ground Vehicles	The LiDAR sensor is reliable to operate in various environmental conditions and still capable of detecting real-time obstacles. The Feed Forward Neural Network used for the intelligence of obstacle avoidance system takes less time in making the right avoidance decision.	
T. E. Baum, J. P. Chobot, K. L. Wolkowicz, and S. N. Brennan	2018	Negative Obstacle Detection Using Lidar Sensors for A Robotic Wheelchair	The LiDAR sensor has different responses to various surface materials. The non-ideal surface such as the dark or shiny	

			surfaces have increased the inconsistency in LiDAR's distance measurement reading for negative obstacles.	
H. Grewal, A. Matthews, R. Tea, and K. George	2017	LIDAR-Based Autonomous Wheelchair	Although LiDAR is beneficial for obstacle detection, one disadvantage of it is that the laser can only scan when it is on a horizontal plane at the height above the user sitting on the wheelchair.	
R. I. Cristian, V. I. Cristian, G. Eugen, R. Horatiu, and B. Lidia-Cristina	2019	Decision Making using Data Fusion for Wheelchair Navigation	LIDAR can move the wheelchair to its desired location at ease and with increased reliability because of its capability to detect in real-time the dynamic obstacles, minimizing the risk of collisions in the wheelchair's pathway.	
D. Hutabarat, M. Rivai, D. Purwanto and H. Hutomo	2019	Lidar-based Obstacle Avoidance for the Autonomous Mobile Robot	The mobile robot has an obstacle avoidance system using LiDAR sensors, which can detect objects in the range of 0.12 to 10.5 meters. The measurement of the LiDAR sensor of the autonomous robot was not affected by the intensity of the	

			ambient light and the color of the objects. The mobile robot can detect colored obstacles, but it cannot detect transparent objects because these objects do not reflect the laser emitted by the LiDAR sensor.	

2.4. Simultaneous Localization and Mapping (SLAM) for Mapping and Navigation System

As stated in [49], various types of electric wheelchairs have been introduced in the research industry and are continually advancing worldwide. Another type is the SLAM-based autonomous wheelchair navigation system. LiDAR-based SLAM algorithms are usually a combined system for a more accurate navigation system of the wheelchair. These algorithms are able to utilize the use of laser scanners to obtain data to combine with the results from odometry localization. After obtaining the said data, the localization of the wheelchair and the static map are constructed. SLAM algorithm provides flexibility to the application of the navigation capabilities for the wheelchair. The SLAM algorithm incorporated with LiDAR gains the capability to use laser scanners for the mapping and localization algorithms. The map constructed is previewed like a 2D occupancy grid of data. The SLAM test focused on the validation of the map construction and localization of the wheelchair in order to collect the data of the navigation system. It was performed in different starting points to correct every error position to match with the newly generated map. To construct a more precise mapping, it is generally proposed to perform a lot of processing, especially for the localization of indoor wheelchairs. There is also the capacity of the processor and the speed of the wheelchairs to be considered in proposing an automated indoor wheelchair. Based on the results of the study, Test 1 produced data where it is seen that the purely based LiDAR and SLAM algorithms such as the Gmapping and Hector SLAM are more capable of generating an accurate 2D map with wall boundaries as well. When it comes to learning more features, Hector SLAM is performing better than Gmapping. For the visual SLAM, the three algorithms (RTAB-MAP, VINS-Mono, and RGB-D SLAM) generated an accurate map despite being given a constraint field of view. The results are somewhat predicted because RTAB-MAP and RGB-D SLAM use identical image features (SIFT, SURF, and ORB), and their mapping is superior to that of VINS-Mono. For Test 2, the mapping of corridors is more accurate with Gmapping than with Hector. It is a predictable result because Gmapping employs wheel odometry data while Hector only relies on observed features, which is troublesome when there are no new features shown. This degrades the future accuracy of the map since the map is not updated due to the lack of newly observed data around the environment of the wheelchair, which results in the loss of the map data. Visual SLAM, on the other hand, is able to form a map out of its environment. Test 3 of the study includes the set trajectory error of the estimated increase in speed of the wheelchair. The study concluded that in order to choose the best localization for the wheelchair's indoor mapping, it must be according to the required operating speed and the computed processor's capacity. Autonomous wheelchairs should consider the preferred speed of the patient for they would be the ones to use the wheelchairs. SLAM for mapping and navigation of the wheelchair should be able to produce a map with features such as obstacle detection to be embedded in the program for better mapping results while simultaneously computing for the localization of the wheelchair. The generated map will then be used for the path planning and navigation of the wheelchair for the indoor environment.

SLAM is an important parameter considered in creating a robotic project. It is used to help the robot know its environment and where it is in the environment. In the study [48], the proponents simulated a virtual environment where a robot is tasked to map its surroundings and navigate to the desired location pinned by the user. They used the Gazebo to simulate both the robot and virtual environment. The robot was attached with the Hokuyo Laser to act as the sensor in generating the map which utilizes Gmapping – considered to be one of the best SLAM algorithms among the others [50]. From the generated map that was created using SLAM, the authors were successfully able to produce the same map created from the simulation. The results of the study showed that the robot was able to navigate to different locations pointed by the authors with and without the simulated obstacles. An obstacle is detected by the robot whenever a foreign material is found from navigating and it is not formerly present in the created map. This prompts the robot to recreate and update the map, and look for an alternative short route to its target point. SLAM is very useful when it comes to indoor navigation of machines such as robots. With the integration of sensors such as LiDAR, RGB-D camera, and IMU (Inertial Measurement Units), the desired subject can map and navigate safely, finding its shortest path to the chosen area of the user [50].

Simultaneous Localization and Mapping (SLAM) is a technology that helps robots to gain knowledge about the environment. By integrating the Light Detection and Ranging (LiDAR) sensor with the SLAM algorithm, the robot can obtain an understanding and build a map of the indoor environment. In the study conducted by Gobhinath et. al. [51], the researchers used RPLiDAR A1, a LiDAR sensor that uses an infrared laser to collect measurements. The digital signal processing (DSP) that is embedded inside the LiDAR processes the data, including the output distance and angle measurements between the object and the sensor. The LiDAR data was used to map locations and make a decision that will allow the robot to navigate its surroundings effectively. By incorporating the SLAM algorithm with the LiDAR sensor, the mobile robot was able to adapt to an unknown environment. In addition, the study utilized the Robot Operating System (ROS) for the active SLAM robot that allows easy integration of packages and equipment. ROS is the major base of the study since it releases messages between the areas and includes a distributed parameter system. ROS has also allowed the researchers to establish a virtual environment, generate robot models, apply various algorithms, and visualize the physical world. The study also measured the wheel motion together with the robot navigation model to determine the robot's position. The inertial measurement unit has also been utilized to calculate the rotation and speed of the robot. The study has successfully developed an autonomous mobile robot that can move around in an indoor environment. The LiDAR in a mobile robot has accurately mapped the unknown surroundings within an 8-meter range. Furthermore, the area of the environment was represented in a coordinate form for easy implementation of autonomous movement.

Table 2.9: Review of Related Literature in Simultaneous Localization and Mapping (SLAM) for Mapping and Navigation System

Author/s	**Year**	**Title of the Paper**	**Relevant Findings**	**Relationship to the Study**
A. Juneja, L. Bhandari, H. Mohammadbagh	2019	A Comparative Study of SLAM Algorithms for	SLAM for mapping and navigation of the wheelchair should be	Both studies aim to use the program

erpoor, A. Singh, and E. Grant		Indoor Navigation of Autonomous Wheelchairs	able to produce a map with features such as obstacle detection to be embedded in the program for better mapping results while simultaneously computing for the localization of the wheelchair. Results show that the purely based LiDAR and SLAM algorithms such as the Gmapping and Hector SLAM are more capable of generating an accurate 2D map with wall boundaries as well	of SLAM Algorithm
R. Kannan Megalingam, C. Ravi Teja, S. Sreekanth, and A. Raj	2018	ROS based Autonomous Indoor Navigation Simulation Using SLAM Algorithm	SLAM is very useful when it comes to indoor navigation of machines such as robots. With the integration of sensors such as LiDAR, RGB-D camera, and IMU the desired subject can map and navigate safely to the desired location.	
S. Gobhinath, K. Anandapoorani, K. Anitha, D. D. Sri and R. DivyaDharshini	2021	Simultaneous Localization and Mapping (SLAM) of Robotic Operating System for Mobile Robots	The study utilizes LiDAR sensor with SLAM algorithm in building a map of the indoor environment. The LiDAR sensor has accurately mapped	

			the surroundings within an 8-meter range. On the other hand, the SLAM algorithm used the LiDAR data to allow the mobile robot to adapt to the unknown environment.	

2.5. Parameters to Consider in Designing a Wheelchair

A lot of parameters are to be considered when making an autonomous wheelchair for the safety of the patient and the smoother performance of the wheelchair itself. One study mentioned another important parameter to be considered is the speed according to the capacity of the processor. This study mentioned that localization of an autonomous wheelchair requires a lot of processing especially when mostly used indoors. The algorithm that will be used for the indoor wheelchairs must consider the computed weight of the processors used in order to set the ideal operational speed of the wheelchair. It is also recommended that the speed would fit best according to the preference of the patient that will use the wheelchair [49].

Some researchers conducted a study regarding the reliability of automated wheelchairs. [52] involved sixteen subjects, eight were women and the other eight were men. The main focus of the study is to assess whether the user is willing to use an automated wheelchair even with the knowledge of possible malfunction of the system. The average suitable speed for the wheelchair was also considered in the study which is an important parameter in considering wheelchair automation. From the results, the approximate average speed for the wheelchair is observed to be around 1.13 m/s or approximately 4.07 km/h. It is safe to say that the speed should be calibrated to about 4 km/h. Considering that the experiment was done outdoors, this speed is applicable when dealing with navigation in an outdoor environment. Furthermore, the willingness of wheelchair users to use an automated vehicle rather than a typical one will depend on the wheelchair's reliability. A supervision system is recommended for automated wheelchairs in order to increase the user's comfort and trust in using the vehicle.

Pawar et. al [53] considered the total mass of the wheelchair and its velocity in illustrating the design and analysis of an electric wheelchair that can also serve as a stretcher. The indicated total mass of the wheelchair, including the load-carrying capacity equivalent to 100 kg, is 145 kg, and the considered velocity is 1.5m/s. For the standard body weight distribution, the upper body weight shares about 68.35% and 18.8% for the thigh weight. In the case where the wheelchair travels along a flat surface, the calculated power required for one wheel is 64.9 Watts. This study of designing a particular wheelchair has considered the weight of the wheelchair users for safety purposes, knowing that wheelchairs also have their limitations and cannot withstand the weights beyond the correct and appropriate calculated weight. Moreover, given the indicated human body weights, the study implies that a wheelchair can be used by people with a weight of up to 100 kg.

Navigation has always been a difficulty for people with physical disabilities. It is a major challenge for patients and their respective assistance providers. This enduring problem has been a great concern in diverse topics of research fields ranging from medical to applied intelligence and a lot more. One study worked up to design an automated wheelchair that innovated further the existing joystick and obstacle detection system by using ANFIS [54]. Stated in this study is their consideration of the load-carrying capacity of the wheelchair frame. The values that the researchers have obtained are then computed in order to acquire the maximum weight carriage of the wheelchair framework. Considering also the factor of safety and the build-up strength of the wheelchair, the computed maximum weight adopted is about 100kg. Using the formula of weight, $w = m \times g = 100 \times 9.81$, this infers that the frame should be able to carry a 981 N load. The study also considered the material selection for the wheelchair framework (mild steel) for the factor of safety. The speed calculation of the wheelchair is also considered in order to suit the preference and also to take note of the patient's safety in using the wheelchair. In order to compute the speed of the wheelchair, the following must be computed; Current of the motor (I) = Motor power/Motor voltage; Torque of the motor = Power x $60/2\pi N$; Front wheel periphery = $2\pi R$; Speed of wheelchair = periphery of front wheel x motor speed. For the future innovations of the study, the researchers recommended incorporating a head gesture sensor for the users who are unable to use a joystick-controlled wheelchair, incorporating voice-controlled features, and a charging system for recharging the battery of the automated wheelchair.

Another journal also briefly discussed the parameters needed to be considered in implementing an automated wheelchair. The study is about the creation of a wheelchair that can help blind people navigate to their desired destination without the supervision of others. Since the study would involve blind patients, it is important to take into account the safety condition of the user by carefully planning the mechanical aspects to be used in the wheelchair [55]. Various calculations were made by the proponents which include the mass and balance of the wheelchair, forces acting on the wheelchair, and torques due to the different parts of the wheelchair. The mass consideration involves not only the physical wheelchair but also the components needed to design the automated vehicle such as the batteries, motors, microprocessor, and circuits. Moreover, the weight of the user is one of the most important factors that determines the performance of the wheelchair. Like the other academic studies regarding automated wheelchairs, a map is created, and an obstacle detection system is included to help in navigating different areas indoors. What makes it unique from similar studies is that QR codes are used for localization instead of using SLAM algorithms. Finally, even if some modifications and additional features are suggested to be done in the future to further improve the work, [56] was able to make the automated wheelchair work while considering the condition of the patient.

One of the parameters that also needs to be considered is the power management of the automated wheelchair. Selecting the appropriate battery is important in designing an automated wheelchair as it can affect the overall weight of the wheelchair and the power supplied to the hardware components in the wheelchair. A study of a new design of an electric wheelchair considered the parameters such as drive and steering, motor, and battery [56]. A 24-V battery was used in the wheelchair since it can provide sufficient power to the motors and other components in the electric wheelchair and has an acceptable additional weight to the wheelchair. Also, this study has stated that wheelchairs commonly use two 12-V batteries to supply 24 volts and two permanent magnets DC motors or PM motors.

Table 2.10: Review of Related Literature in Parameters to Consider in Designing a Wheelchair

Author/s	Year	Title of the Paper	Relevant Findings	Relationship to the Study
A. Juneja, L. Bhandari, H. Mohammad-bagherpoor, A. Singh, and E. Grant	2019	A Comparative Study of SLAM Algorithms for Indoor Navigation of Autonomous Wheelchairs	The algorithm that will be used for the indoor wheelchairs must consider the computed weight of the processors used in order to set the ideal operational speed of the wheelchair.	Both studies consider the load carrying capacity of the wheelchair
N. Hashimoto, K. Tomita, A. Boyali, Y. Takinami, and O.	2018	Experimental study of the human factors when riding an automated wheelchair: Supervision and acceptability of the automated system	The approximate average speed for an automated wheelchair in an outdoor environment is observed to be around 1.13 m/s or approximately 4.07 km/h.Thus, the speed should be calibrated to about 4 km/h.	Both studies consider the load carrying capacity of the wheelchair
S. Pawar, Y. Kanade, H. Singh	2021	Design and Analysis of Electric Wheelchair cum Stretcher	For the standard body weight distribution, the upper body weight shares about 68.35% and 18.8% for the thigh weight. In the case where the wheelchair travels along a flat surface, the calculated power required for one wheel is 64.9 Watts.	Both studies consider the load carrying capacity of the wheelchair
M. Okwu, L. Tartibu, M. Ayomoh, and D. Ighalo	2020	Development of an Autonomous Wheelchair for the Disabled and Performance Analysis Using ANFIS Model	Stated in this study are their consideration for the load carrying capacity of the wheelchair frame. The values that the researchers have	Both studies consider the mechanical aspects in modifying a wheelchair

			obtained are then computed in order to acquire the maximum weight carriage of the wheelchair framework.	
A. Siddiqui et al.	2018	Development of an Automated Wheelchair for Visually Impaired People	It is important to take into account the safety condition of the user by carefully planning the mechanical aspects to be used in the wheelchair. Parameters to be considered are the mass and balance of the wheelchair, forces acting on the wheelchair, and torques due to the different parts of the wheelchair.	
J. Kaňuch	2017	Direct Drive of Electric Wheelchair with Double Disc BLDC Motor	Wheelchairs commonly use two 12-V batteries to supply 24 volts and two permanent magnets DC motors or PM motors. A 24-V battery was used in the wheelchair since it can provide sufficient power to the motors and other components in the electric wheelchair and has an acceptable additional weight to the wheelchair.	

Chapter 3

METHODOLOGY

This chapter presents the research design, research process flow, modification of wheelchair through the integration of sensors, microprocessor, and microcontroller for control and automation, development of indoor routing indoor navigation feature via SLAM algorithm and LiDAR technology, development of the voice-control system, user acceptance and actual field testing, statistical analysis, and project work plan.

3.1. Research Design

The study utilized a developmental research design to innovate existing wheelchairs further. The main focus is to design a voice-controlled wheelchair incorporated with an auto-navigation system to increase the quality of life of patients suffering from poliomyelitis, quadriplegia, those with spinal cord injuries, and the elderly. The design implements a LiDAR sensor installed on the wheelchair to collect data on the indoor floor area. The gathered data points were used and processed to create the map for the auto-navigation system. The voice recognition module V3 was used to recognize the recorded voice of the user, that controls the DC motors of the wheelchair. Moreover, a descriptive research design was implemented by conducting an interview with the wheelchair users and tests from Tahanang Walang Hagdanan, Inc. and Bigay Buhay Multipurpose Cooperative. The interview aims to gather information about the insights of wheelchair users and how they will benefit from the proposed study. Moreover, different experts were consulted regarding the overall design of the voice-controlled wheelchair. The electronics engineers assessed the electronics parts of the system, the electrical engineer examined the circuitry and power management, and the mechanical engineer evaluated the mechanical hardware part of the automated wheelchair.

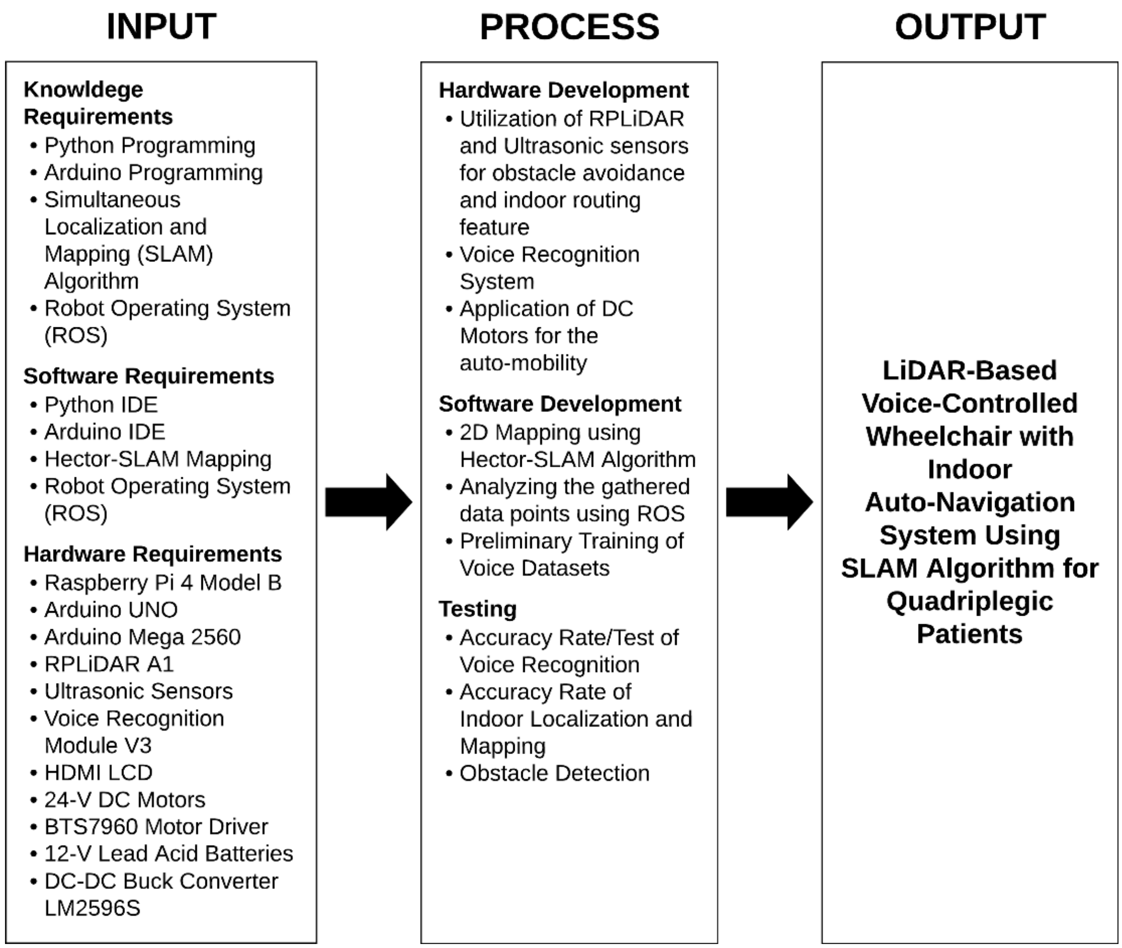

Figure 3.1: Input – Process – Output Diagram

3.2. Research Process Flow

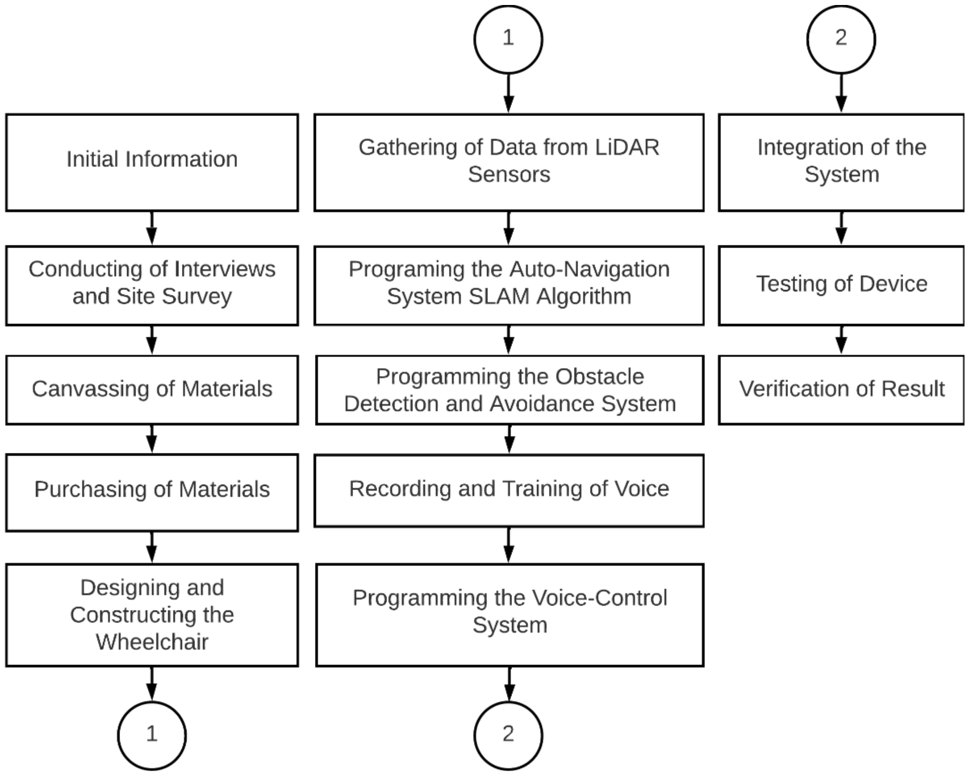

Figure 3.2: Research Process Flow of the Proposed Methodology

3.3. Modification of Wheelchair through Integration of Sensors, Microprocessor, and Microcontroller for Control and Automation

3.3.1. Determining and purchasing required sensors and equipment to be used in the automated voice-controlled wheelchair with auto-navigation

ChairLiDAR is composed of a single-board computer, microcontrollers, sensors, and other hardware components to work according to its supposed function. The research study utilized the following hardware components in designing the voice-controlled wheelchair with an auto-navigation system.

- Microprocessor Unit

The proponents incorporated a Raspberry Pi 4 Model B with 4GB RAM. This provides high-speed and high memory, which is necessary for the implementation of mapping, voice recognition, and overall performance of the wheelchair. The Raspberry Pi 4 runs a 64-bit quad-core memory and serves as the system's brain since it contains all the codes for the voice recognition system, auto-navigation through SLAM, obstacle avoidance, and vehicle control system [57].

Figure 3.3: Raspberry Pi 4 Model B

- Microcontroller Unit

The Arduino UNO microcontroller was connected to the Raspberry Pi microprocessor as it served as the controller mainly for the DC motors of the wheelchair. It is powered at 5 volts, which enables its user to utilize 14 I/O pins. The microcontroller also has 32 KB of flash memory, 2 KB of SRAM, 1KB of EEPROM, and 16 MHz of CLK speed [58].

Figure 3.4: Arduino UNO

The Arduino Mega 2560 microcontroller was connected to the Raspberry Pi microprocessor as it served as the controller for the voice recognition module. The input from the voice recognition module is sent to Arduino Mega to produce digital output, and the digital output is transferred to the Raspberry Pi.

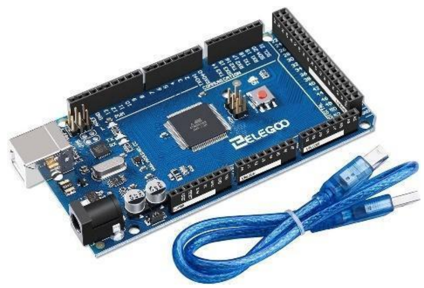

Figure 3.5: Arduino Mega 2560

- Sensors

The function of the RPLiDAR is to collect data on a particular location by emitting a laser pulse to the indoor area. The laser generates accurate information and creates a 2D map needed to implement the auto-navigation and anti-collision systems of the wheelchair. It is the sensor for implementing the system since it is unaffected by environmental factors such as light variations and can still operate in low light conditions [59].

Figure 3.6: RPLiDAR A1

Ultrasonic sensors are additional obstacle detection sensors for higher accuracy of detecting static obstacles as well as the negative obstacles present in the environment. These sensors emit a short ultrasonic pulse or an ultrasonic wave to detect the present obstacles in the environment, and receive the reflected echo from that detected object. The distance between the detected obstacle and the sensor is measured by the time taken of the emitted ultrasonic wave to reach the object and its return to the sensor which is the echo [60].

Figure 3.7: Ultrasonic Sensor HC SR04

- HDMI LCD

A 7-inch LCD monitor allows the system to start without requiring it to connect to a separate workstation. It also allows the user to set an estimate position from the map to ensure localization accuracy.

Figure 3.8: 7-inch HDMI LCD

- Actuator

24-V DC motors were chosen for maneuvering the wheels according to the navigation-voice command and possible avoidance direction when an obstacle is detected. The ATmega328 Arduino activates it after receiving instructions from the microprocessor.

Figure 3.9: 24-V DC Motor

- Steering System

Two motor drivers of 6V-27V with 43A were used to control the movement and speed of the DC motors of the wheelchair.

Figure 3.10: Motor Driver 43A BTS7960

- Power Supply

Two 12-V lead-acid batteries serve as the power source of the automated wheelchair to supply a total of 24 volts in the system.

Figure 3.11: 12-V Lead Acid Battery

3.3.2. Designing the structure of the prototype

The overall design of the wheelchair considered both mechanical and placement of the hardware components. For the mechanical part, the proponents consulted a mechanical engineer to know the appropriate mechanical factors to be considered in modifying the wheelchair. The proposed design consists of various devices and sensors, such as the Raspberry Pi, Arduino, LiDAR sensor, ultrasonic sensors, voice recognition module, DC motors, motor driver and buck converter. The LiDAR sensor was attached to an adjustable pole placed behind the left handle of the wheelchair to cover all sides of the environment. It is vital in generating a map and obstacle detection. Moreover, the voice recognition module, along with the microphone, was placed below the right armrest of the wheelchair, for capturing the user's voice. The remaining components needed to build an automated wheelchair, such as the Raspberry Pi 4 B, Arduino, DC motors, motor drivers, and buck converter were placed at the rear part of the wheelchair, and the two 12-V lead-acid batteries were secured and placed below the seat.

3.3.3. Constructing the proposed wheelchair design and integrating the hardware components

Once the design of the wheelchair was finalized, the purchased materials and equipment were integrated to create the prototype of the proposed system. The mechanical parts of the wheelchair were first modified according to the plan suggested by the mechanical engineer. After the structure of the wheelchair was completed, the hardware components were installed in their respective placements based on the conceptualized design of the wheelchair. The sensors, microcontroller, transducer (microphone), and actuators were integrated with the Raspberry Pi microprocessor since it is the one that processes the inputs and keeps the communication between the connected components and the program.

3.4. Development of Indoor Routing Navigation Feature via SLAM Algorithm and LiDAR Technology

3.4.1. Gathering of data using RPLiDAR sensors

The primary stage of generating a map is data gathering of the RPLiDAR sensor. The proponents mapped the area (navigate the surroundings) with use of the RPLiDAR sensor through Hector SLAM. The obtaining of data is the extraction of features of the indoor environment. The RPLiDAR sensor collects the data by emitting laser beams to the indoor surroundings. The time the laser beams take to return to the LiDAR sensor itself after reflecting on a surface determines the distance between the sensors and the indoor surfaces.

3.4.2. Programming of the auto-navigation system using SLAM algorithm

Hector-SLAM validates the map construction and localization of the wheelchair in the indoor environment. It has an advantage over other SLAM techniques, requiring only laser scan data to function [61]. To be able to apply and use the Hector-SLAM algorithm, the Robot Operating System (ROS) was used to analyze the data and communicate with the wheelchair from a laptop. ROS is a versatile framework for developing robot software. It is a set of tools, libraries, and conventions which are designed to make it easier to create complex and robust robot behavior across a wide range of robotic platforms. ROS was built from the ground up to encourage collaborative robotics software development [62].

ROS uses the operating system's process management, user interface, file system, and programming tools. The mapping will be visible in the RViz application. In constructing and updating the map, the SLAM algorithm simultaneously tracks the current location of the wheelchair. The map generated from the SLAM algorithm will then be used for path planning and indoor navigation of the wheelchair.

3.4.3. Programming the Obstacle Avoidance

The proponents integrated the RPLiDAR sensor with two ultrasonic sensors for the obstacle detection and avoidance system. Through ROS (Robot Operating System), the separate programs for the obstacle detection of RPLiDAR sensor and ultrasonic sensors were able to communicate with each other to execute their purpose of detecting an obstacle. The Robot Operating System is an open source that contains multiple libraries and tools for creating, building, and executing programs to operate and control a robot [63]. The program for obstacle detection using RPLiDAR includes ROS Navigation Stack which contains packages that help a mobile robot to move around and go to a desired location safely [64]. This navigation stack was used in the auto-navigation system of the wheelchair and includes a package called move_base that enables the navigation of a robot in attempting to reach a goal or location through path planning as well as including an obstacle layer parameter in one of its launch files for safe navigation. The move_base associates global planner with a local planner for path planning. As the RPLiDAR sensor detects an obstacle, the obstacle_layer parameter and path planners in move_base package acts upon the detection by sending a message about the detected obstacle and the calculated path plan to the program that contains the controlling of wheels through the ROS topic cmd_vel. The cmd_vel ROS topic serves as the bridge for the communication of the programs for obstacle avoidance and steering of wheels of the wheelchair. Since the RPLiDAR sensor was placed at an adjustable pole, which is elevated, there were additional two ultrasonic sensors to detect obstacles below the scanning range of the RPLiDAR sensor in the operating area. The first one was mounted on the left armrest and the second ultrasonic sensor was placed at the back of the wheelchair.

The program for obstacle avoidance using ultrasonic sensors was created using arduino programming. This program contains the conditions where the ultrasonic sensors measure the distances of the obstacles and decide in which direction the wheelchair should go based on the accumulated distance measured from left and right direction.

3.4.4. Initial testing of the programmed auto-navigation system and obstacle avoidance system

After programming the LiDAR sensor, the proponents conducted initial testing on a mobile robot. This LiDAR sensor, which was initially placed on a wheelchair, has acquired data points of the location considering the dimension of the wheelchair. The sensors for the program of auto-navigation and obstacle detection systems were incorporated in a mobile robot to execute the initial testing using the data collected by the LiDAR. The mobile robot used the generated map of a particular indoor space to perform the auto-navigation feature. During the initial testing implemented on a mobile robot, the proponents evaluated and verified the accuracy of auto-navigation system and obstacle avoidance feature.

3.5. Development of Voice-Control System

3.5.1. Gathering of data for voice recognition feature

The proponents aim to obtain voice data from any of the researchers to test the voice recognition feature of the system. The series of recordings contains the user dictating the voice-control commands such as “forward,” “backward,” “left,” “right,” and “stop,” and the necessary locations from the mapped area of the user. This data was utilized for the system’s voice recognition feature, essential for ensuring the patient’s safety.

3.5.2. Training the Voice Recognition System

The proponents trained sample voice commands using the code for voice training. After training the sample voice commands, the recorded voice command was stored in the recognizer, and these recorded sample voices were used to control the DC motors and movement of the wheelchair.

3.5.3. Programming the Voice-Control System

The program of the voice-control system is responsible for prompting the wheels to move according to the direction of voice commands given by the user. There are default voice commands in this program, which are “forward,” “backward,” “left,” “right,” and “stop.” Also, the names of the location within the mapped indoor area were the additional voice commands in the program; this is for the auto-navigation feature of the designed wheelchair. Once the user speaks the navigation command or the location's name, the wheelchair will automatically move to that location.

3.5.4. Initial testing of the programmed voice-control system

The created program for the voice-control system was tested in a mobile robot to ensure the system is working properly. The commands— “forward,” “backward,” “left,” “right,” or “stop”— dictated by the proponent whose voice was used, and the robot’s actions were evaluated whether it followed the correct command or not. This served as a confirmation if the system works only for the speaker. Additionally, the test determined whether it will work even in a noisy environment. Necessary troubleshooting was implemented when the system fails to execute the proper command.

3.6. User Acceptance and Actual Field Testing

3.6.1. Conducting of site survey on the location of implementation

The proponents conducted a site survey on Tahanang Walang Hagdanan, Inc. in Cainta, Rizal and Bigay Buhay Multipurpose Cooperative in Quezon City, to determine the possible locations of where the wheelchair can be implemented. Moreover, conducting a site survey can help the proponents to determine the considerations needed for the user's safety when using the wheelchair. By verifying and checking the circumstances in the location of deployment sites, the proponents were able to confirm the possible limitations of the wheelchair such as the high elevated steps, huge humps, ramps, and so on. Hence, the proponents considered some modification of the wheelchair for the safety of the user.

3.6.2. Initial testing of the whole system

The initial testing was implemented first on mobile robots for easy control. Following the assembling of different subsystems on the mobile robot, multiple testing were conducted. First, one of the proponents' voices was used as an input to the voice recognition system. The proponents observed and verified whether the mobile robot follows the command, from which the voice data was extracted, by monitoring the screen for the corresponding string message of the command. The capability of the voice recognition system was tested by trying to command the mobile robot using the voice of another person. Another mobile robot was utilized for the initial testing of the auto-navigation system wherein the 2D-nav goal function in the RViz visualization tool was used to enable the robot to navigate through its provided path based on the set goal or destination. Reaching the goal based on the 2D-nav goal was the basis of the testing and verifying of the auto-navigation feature. Moreover, the researchers assessed the performance of the obstacle avoidance system by observing the mobile robot's decision when it encounters obstacles.

3.6.3. Utilization of the system prototype

After confirming that the initial testing of the whole system using the mobile robot was successful, the researchers integrated the system into the modified wheelchair. Verification and validation techniques were applied to the wheelchair to test if the active hardware components were wired, and if the software setup is correctly running. The researchers implemented the generated indoor routing navigation of the wheelchair into one of the proponents' test locations (e.g., house, apartment, or any private location). Subsequently, the researchers used the sampled voice command on the test location. One of the proponents acted as the user of the wheelchair and assessed it by conducting different voice commands. Several test cases were conducted to optimize the configuration files against the performance measures and evaluate the results.

3.6.4. Actual field testing of the prototype

After the prototype testing in the researchers' area, user acceptance testing (UAT) was implemented at Tahanang Walang Hagdanan, Inc. and Bigay Buhay Multipurpose Cooperative wherein some of their wheelchair users evaluated the working model to validate if the proposed study will be helpful for quadriplegic patients. In addition, UAT helped the proponents to know the insights and recommendations of wheelchair users to improve the design of the wheelchair.

3.7. Statistical Analysis

The research used a descriptive analysis considering the accuracy of the voice-controlled wheelchair's performance. Multiple trials were conducted to gather data regarding voice recognition and auto-navigation features. The voice recognition accuracy was determined by calculating its overall average from the number of successful voice command recognitions in the conducted 30 trials for each basic command and 10 trials for each destination command. Similarly, the accuracy of auto-navigation feature was obtained by calculating the average number of successful wheelchair arrivals at the desired destinations within the mapped indoor area, with each destination undergoing 10 trials.

3.8. Project Work Plan

Table 3.1: Gantt Chart

ACTIVITY DESCRIPTION	MONTH 1	MONTH 2	MONTH 3	MONTH 4	MONTH 5	MONTH 6	MONTH 7	MONTH 8
Determining and purchasing required sensors and equipment to be used in the automated voice-controlled wheelchair with auto-navigation								
Designing the structure of the prototype								

Constructing the proposed wheelchair design and integrating the hardware components								
Gathering of data using RPLiDAR sensors								
Programming of the auto-navigation system using SLAM algorithm								
Programming the Obstacle Avoidance System								
Initial testing of the programmed auto-navigation system and obstacle avoidance system								
Gathering of data for voice recognition feature								
Training the Voice Recognition System								

Programming the Voice-Control System								
Initial testing of the programmed voice-control system								
Initial testing of the whole system								
Utilization of the system prototype								
Actual field testing of the prototype								

Chapter 4

DATA AND RESULTS

4.1. Project Technical Description

The project aims to develop a wheelchair with voice-controlled navigation capabilities for improved mobility and enhanced quality of life, specifically catering to quadriplegic patients. This innovative wheelchair allows users to independently control their movements through voice commands, encompassing basic functions such as forward, backward, left, right, and stop and destination commands corresponding to specific locations within the mapped indoor area.

To achieve this, a commercially available manual wheelchair was modified to incorporate the proposed design. Customizations involved integrating enclosing cases for the battery and other hardware components, such as brushed DC motors. An adjustable pole and mechanical parts were also attached to facilitate operation. Additionally, a socket was included beneath the seat to facilitate convenient battery charging. Furthermore, additional ultrasonic sensors contribute to obstacle detection in areas where the lidar sensor's scanning capacity is limited due to its placement. The voice recognition module and a wired microphone are positioned under the right armrest for easy access and voice input.

In order to address emergencies or system malfunctions, an emergency switch has been incorporated into the design of the wheelchair. Positioned at the lower left side of the wheelchair, this switch provides the user with a manual means to deactivate the entire automated system of the wheelchair. The user can swiftly and effectively shut down all automated functionalities by activating this switch, ensuring immediate control and safety in critical situations.

4.2. Project Structural Organization

The design developed for ChairLiDAR is a modified wheelchair with indoor auto-navigation and voice-control features. Its purpose is to improve the quality of life for wheelchair users, particularly quadriplegic patients. The ChairLiDAR has approximate dimensions of 0.44m in length, 0.6m in width, and 0.8m in height, with an estimated weight of 33 kilograms. The speed of the wheelchair is manually set using Pulse Width Modulation (PWM), and the current default PWM setting is 150. The battery charge may affect the speed of the wheelchair. Therefore, the speed is at full capacity if the battery is fully charged. Moreover, the speed will decrease as the battery discharges. It is designed to transport wheelchair users with a maximum weight of 80 kilograms. Figure 4.1 shows the finished and modified wheelchair of ChairLiDAR, integrated with sensors and modules.

Figure 4.1: Modified ChairLiDAR Wheelchair

4.3. Project Evaluation

4.3.1. Testing of Voice Recognition and Navigation Systems

The testing of the voice recognition system is presented below based on different trials. As shown in Figure 4.2, the voice recognition module was undergoing training with the actual user's voice commands. The wheelchair user repeated each voice command multiple times to the Voice Recognition Module until it successfully recognized and stored the trained commands.

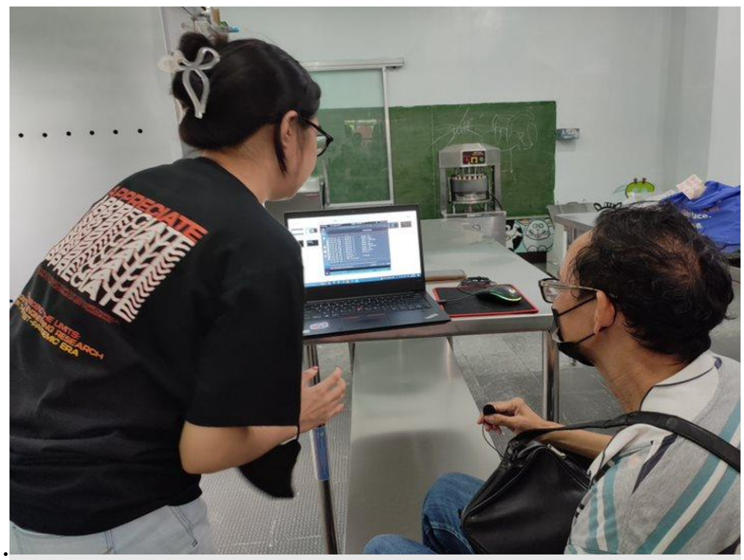

Figure 4.2: Training of Voice Commands in Voice Recognition Module

The voice recognition system's accuracy was evaluated through different types of trials in an actual environment, which included the presence of external noise. Each user underwent 30 trials for every basic command. In every trial, the user will command the wheelchair using the corresponding basic commands such as forward, backward, left, right and stop to move within the vicinity of the map. The initial set of trials involved researchers, with one member assuming the role of the user. The subsequent three sets of trials were conducted by actual users from

Tahanang Walang Hagdanan, Inc. (TWH) and Bigay Buhay Multipurpose Cooperative (BBMC).

Figure 4.3: Voice Recognition Trials for Basic Commands

Table 4.1: Comparison of Voice Recognition for Basic Commands Trials for Each User

30 Trials	Researchers		User 1		User 2		User 3	
Basic Commands	**No. of Success**	**Accuracy (%)**	**No. of Success**	**Accuracy (%)**	**No. of Success**	**Accuracy (%)**	**No. of Success**	**Accuracy (%)**
Forward	27	90.00%	5	16.67%	17	56.67%	13	43.33%
Backward	20	66.67%	12	40.00%	7	23.33%	13	43.33%
Left	29	96.67%	4	13.33%	10	33.33%	18	60.00%
Right	28	93.33%	11	36.67%	12	40.00%	24	80.00%
Stop	22	73.33%	2	6.67%	4	13.33%	7	23.33%

Table 4.1 presents the overall accuracy rate of the basic commands which is based on the 30 trials of each user in speaking each command after the training. The results obtained from researchers indicate a relatively high level of accuracy for most of the basic commands. The forward command obtained the accuracy of 90% which showcases the system's ability to recognize and execute this command effectively. The high accuracy observed for the left and right commands − 96.67% and 93.33%, respectively, further supports the performance of the system in

executing these navigational instructions. However, the accuracy for the backward command and stop command suggests potential areas for improvement in interpreting and executing these specific commands. In contrast, the combined accuracy results for users 1, 2, and 3 demonstrate a lower level of accuracy across all basic commands. Some factors may have contributed to the observed discrepancies between the basic command accuracy rates of the researcher and users such as the way of providing voice inputs during the training and environmental conditions.

Figure 4.4: Voice Recognition Trials for Auto-Navigation Commands

The voice recognition for auto-navigation system's accuracy was evaluated through different types of trials in an actual environment, one which included the presence of external noise. Each user underwent 10 trials for each room/location command (e.g., one/kitchen, two/CR). In every trial, the user will command the wheelchair using the corresponding destination command of the locations stored on the map which, in this case, are Room One and Room Two. Room One represents the Kitchen in the first deployment area, Tahanang Walang Hagdanan, Inc. (TWH), and destination point 1 in Bigay Buhay Multipurpose Cooperative (BBMC). Room Two represents the Bathroom in TWH, and destination point 2 BBMC. The initial set of trials involved researchers, with one member assuming the role of the user. The subsequent three sets of trials were conducted by actual users from TWH and BBMC.

Table 4.2: Comparison of Voice Recognition for Auto-Navigation Commands of Each User

10 Trials	Researchers		User 1		User 2		User 3	
Auto-Navigation Commands	No. of Success	Accuracy (%)	No. of Success	Accuracy (%)	No. of Success	Accuracy (%)	No. of Success	Accuracy (%)
Room 1/Kitchen	9	90.00%	7	70.00%	3	30.00%	10	100.00%
Room 2/CR	7	70.00%	3	30.00%	7	70.00%	6	60.00%

Table 4.2 presents the accuracy of auto-navigation for each user. The testing for the performance and accuracy of auto-navigation system was conducted in 10 trials for each user. As the user speaks the destination command, the accuracy of auto-navigation was evaluated based on its capability of reaching that specific destination. The highest accuracy recorded for Room One is 100%, which means that User 3 always reached his desired destination whenever he says the command for Room One, while User 2 only obtained an accuracy of 30% for the same destination. On the other hand, for Room Two, Researchers and User 2 have the highest accuracy, which is 70%, while User 1 only obtained an accuracy of 30%.

Table 4.3: Summary of Voice Recognition Trials for Basic Commands

Total of 120 Trials	Users	
Basic Commands	**No. of Success**	**Accuracy (%)**
Forward	62	51.67%
Backward	52	43.33%
Left	61	50.83%
Right	75	62.50%
Stop	35	29.17%

Table 4.3. shows the overall result for the accuracy of basic commands recognition which are obtained from the total number of 120 trials for all the users. The accuracy of the right command was measured at 62.5%, which has the highest accuracy among the basic commands. While this accuracy may not be perfect, it indicates a reasonable level of performance for this basic command. Whereas, the accuracy of the stop command has the lowest accuracy, which has a rating of 29.17%. This indicates that ChairLiDAR faced some challenges in accurately interpreting and executing the stop command. The remaining commands – forward, backward, and left, acquired the accuracy of 51.67%, 43.44%, and 50.83%, respectively. The performance of ChairLiDAR in recognizing basic commands has a relatively satisfactory accuracy for some commands, such as right, forward, and left, while facing challenges with other commands, such as backward, and stop.

Table 4.4: Summary of Voice Recognition Trials for Auto-Navigation Commands

Total of 40 Trials	Users	
Auto-Navigation Commands	**No. of Success**	**Accuracy (%)**
Room 1/Kitchen	29	72.50%
Room 2/CR	23	57.50%

Table 4.4 shows that the overall testing of auto-navigation system resulted in different accuracy rates for each destination command in the conducted 10 trials for each user. The destination command Room One obtained the highest accuracy

of 72.5% while Room Two acquired an accuracy rate of 57.5%. These results highlight the need for improvement in ChairLiDAR's navigation accuracy. However, the system still demonstrates a moderate level of performance in successfully reaching the specified targets.

4.3.2. Battery Charging and Consumption

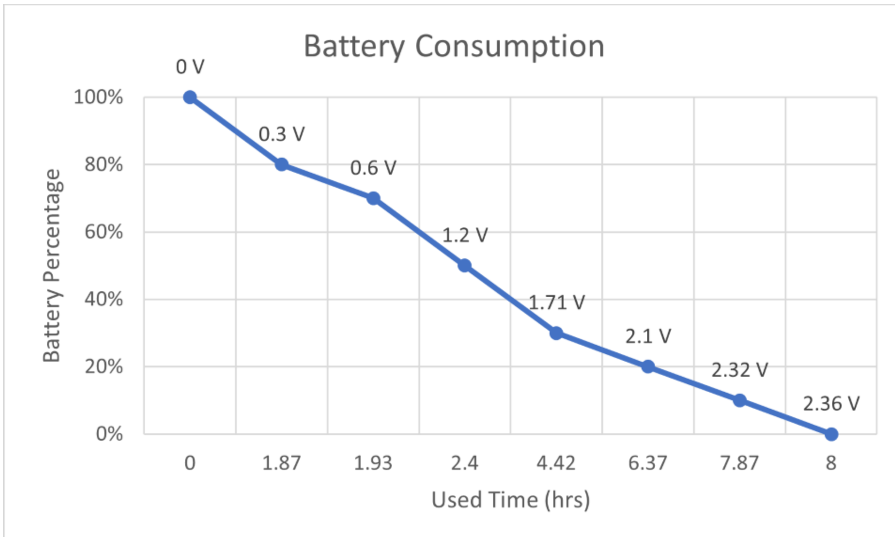

Figure 4.5: Battery Consumption

The following graph illustrates the battery consumption as plotted against usage time and battery percentage. Based on the results, the battery consumption increases as the time usage increases, thus, a decline in the battery percentage. This result indicates that the data for time usage and battery consumption are proportional with each other. Hence, as long as the wheelchair is active, the battery consumption increases.

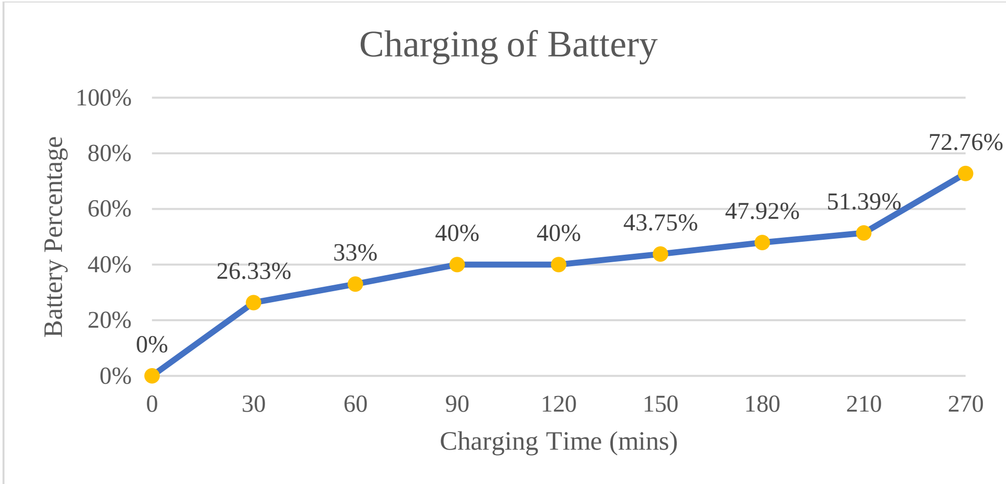

Figure 4.6: Charging of Battery

Figure 4.6 shows the data summary of the charging time of the batteries of the wheelchair. The researchers measured how long it takes for the batteries to be fully charged. The researchers started measuring the voltage at 23.3 V, which is said to be at 0% battery capacity, and continuously measured the batteries at the time interval of 30 minutes. After the first 30 minutes of charging, the 0% battery capacity becomes 26.33%. Then the battery percentage becomes 72.76% after four hours of charging. Based on the gathered results, the batteries take approximately 5 to 6 hours to be fully charged.

Chapter 5

CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

Modifying of commercially available wheelchair, integrating the necessary components, and developing voice control and auto-navigation systems in the proposed design enabled the proponents to attain the main objective of this study, which is to develop an automated wheelchair using LiDAR technology for the indoor auto-navigation feature. This allows the wheelchair user to move around without the need for assistance from another person. The design of the prototype considered various factors that can affect the overall performance of the system. Some of these factors are the scanning capacity of the LiDAR sensor and noise generated by the brushed DC motors. The scanning ability of the LiDAR sensor was maximized by placing it on an adjustable pole, and its capacity to scan the present obstacle was aided by the two additional ultrasonic sensors. The noise generated by the brushed dc motors was reduced after installing an enclosure case with noise-suppression foam for the DC motors and other circuitry.

A framework for providing a variety of packages for robotics called Robot Operating System (ROS) was mainly used by the researchers to achieve the auto-navigation feature of the ChairLiDAR. HectorSLAM is implemented and used for the Simultaneous Localization and Mapping algorithm of the wheelchair that helped the system identify its location in the pre-made map while navigating to another place. This setup proved that the prototype can plan and create a safe plan to navigate the wheelchair to the user's desired location. The utilization of a voice recognition module is also attributed to accomplishing the other objective of the study.

In the voice-recognition feature, the results for each user differ due to various factors affecting its accuracy such as the background noise present in the environment and how the user pronounces the command compared to how it is being trained. The differences in accuracy could be variations in the training data that might have an impact on the system's ability to accurately recognize certain instructions.

For the auto-navigation accuracy, the difference in accuracy between the researchers and users may be due to the weight discrepancy, as researchers were lighter. Modifying the PWM values to accommodate heavier weights affects wheel rotations and impacts the intended path, making navigation more challenging for the wheelchair.

Although the system still has several rooms for improvement due to the mechanical and technical parts that the researchers overlooked, it has promising results as the researchers were able to accomplish the ChairLiDAR as a voice-controlled wheelchair. Implementing the auto-navigation feature alongside with the voice recognition system proved to help create a much convenient and safe way for persons with disabilities (PWDs), especially quadriplegic patients or even the elderlies, navigate to another place while enjoying their independency.

5.2. Recommendations

Developing mobility aids, such as creating automated wheelchairs, for people with disabilities requires extensive research to ensure the safety of the user. For further development of this research, the following are the suggestions and recommendations from the researchers, experts, as well as wheelchair users, which can be useful for future studies:

1. Enhancement of programs for localization and auto-navigation feature.

2. Utilization of a more advanced microprocessor to make the programs operate more effectively.
3. Integration of wheel encoder to monitor the rotation of the wheels.
4. Implementation of automatic startup of the system upon turning ON the wheelchair.
5. Automatic speed adjustment feature based on the weight of the user.
6. Integration of battery indicator to monitor the battery level of the wheelchair.
7. Consider using a brushless motor to lessen acoustic noise.
8. Utilization of deep learning and using of microphone with noise suppression to further improve the voice recognition system.
9. Incorporating fall detection system to ensure the safety of the user.
10. Consideration of having an additional controller, aside from the main controller, allowing the user to have other options to control the wheelchair.
11. Integration of emergency or safety shutdown mechanism for additional safety level of the wheelchair when there is a malfunction encountered.
12. Attachment of anti-tippers at the lower back of the wheelchair to secure the welfare of the user and stability of the wheelchair.
13. Adding bumpers for further safety measures.
14. Proper calibration of front wheels for safe and accurate navigation.

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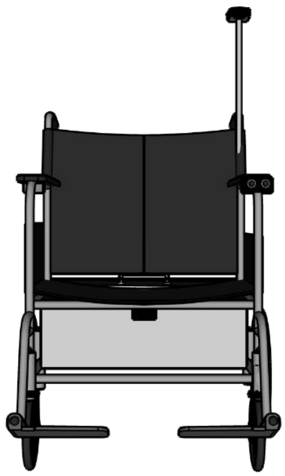
Annex I

Model Design

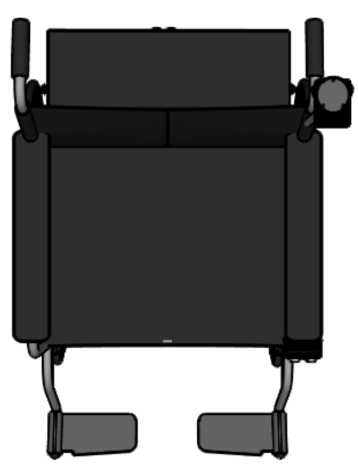


FRONT VIEW

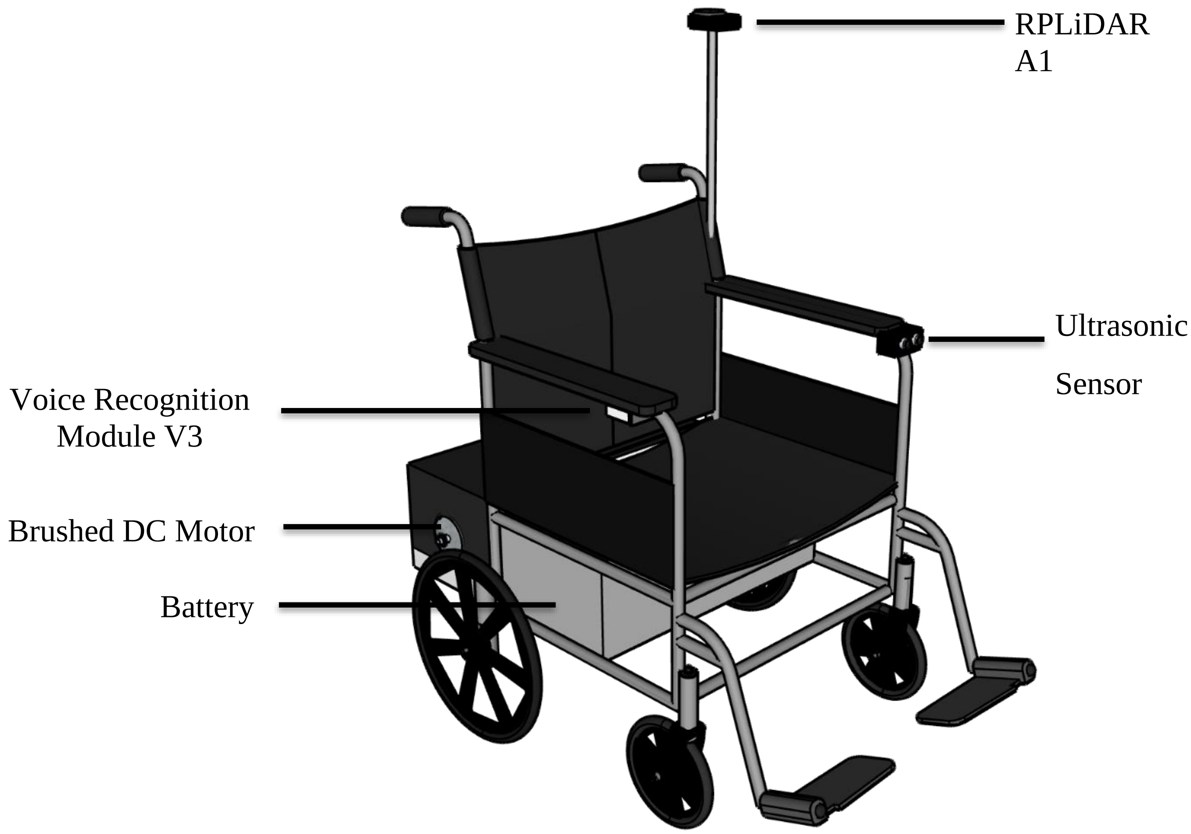
REAR VIEW

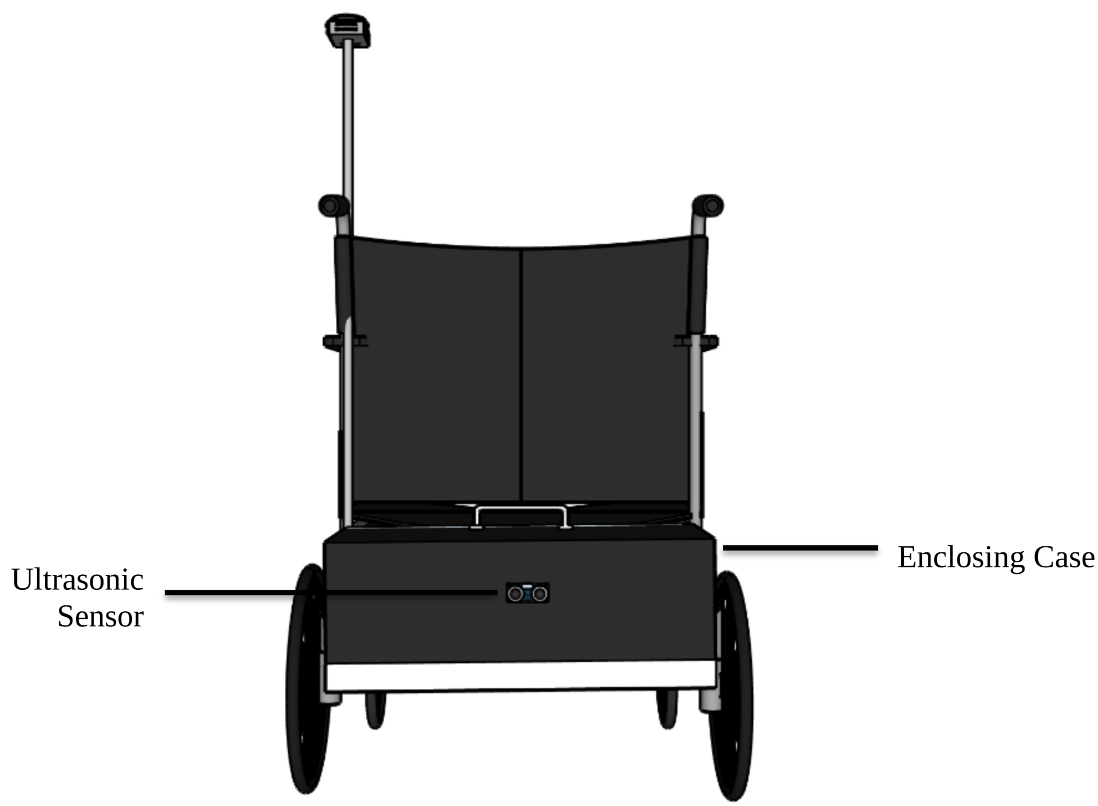
RIGHT SIDE VIEW

LEFT SIDE VIEW



TOP VIEW

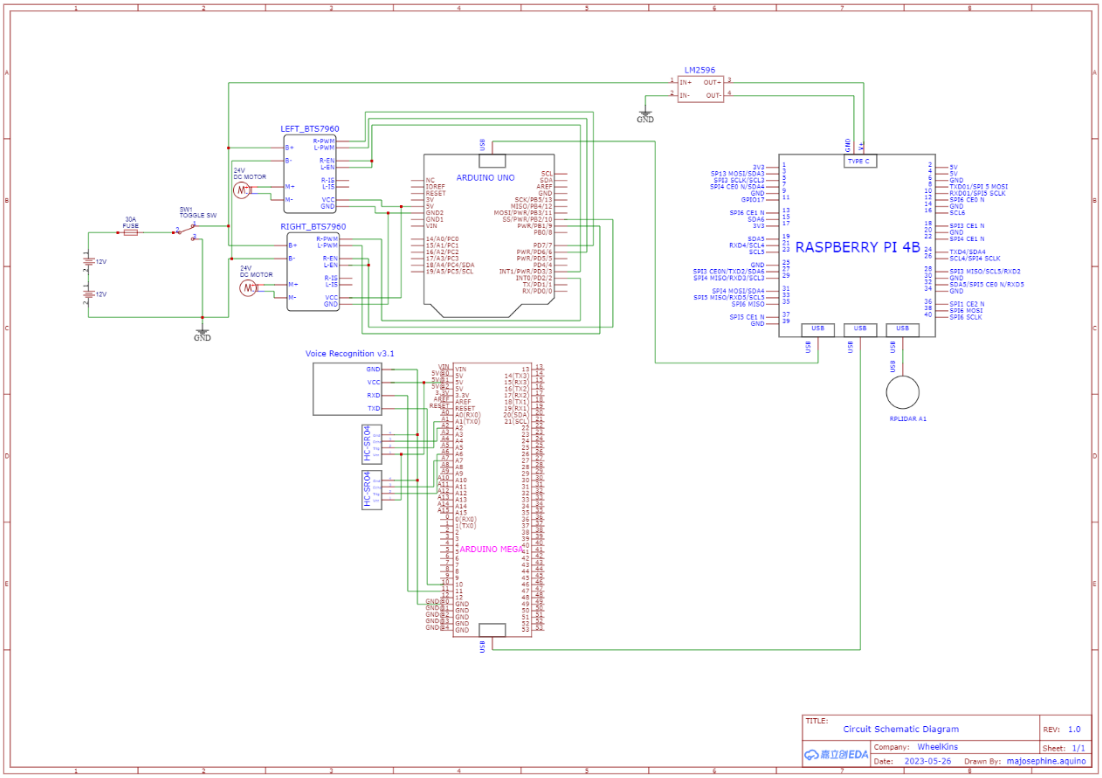

RPLiDAR A1
Ultrasonic
Sensor
Voice Recognition Module V3
Brushed DC Motor
Battery


Enclosing Case
Ultrasonic Sensor

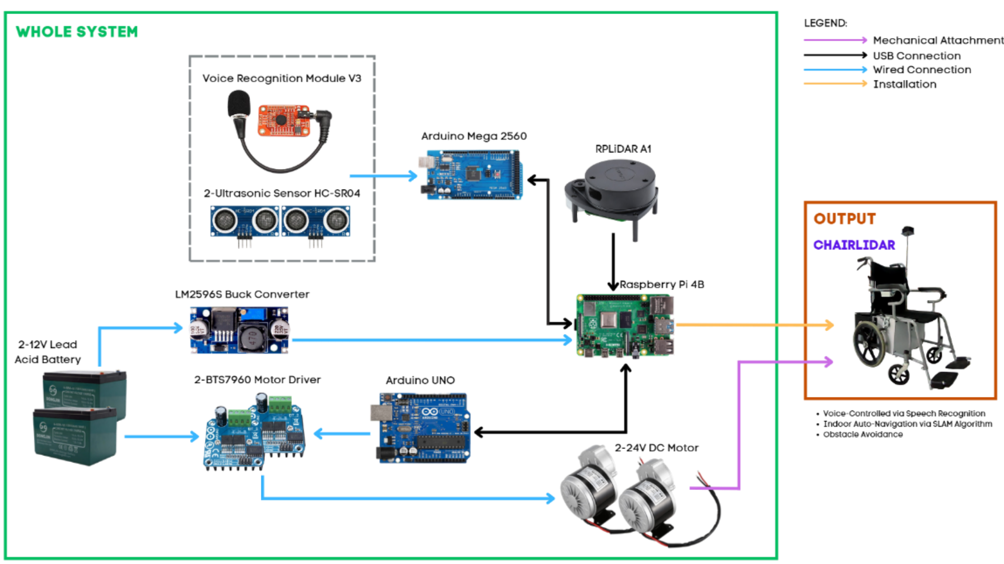
Annex II

System Diagrams

SCHEMATIC DIAGRAM



SYSTEM BLOCK DIAGRAM



Annex III

ChairLiDAR Codes

VOICE RECOGNITION SYSTEM

Arduino Codes for Sending Voice Data to ROS

```
#include <SoftwareSerial.h>
#include "VoiceRecognitionV3.h"
#include <ros.h>
#include <std_msgs/String.h>
ros::NodeHandle nh;
std_msgs::String str_msg;
ros::Publisher chatter("chatter", &str_msg);

VR myVR(10, 11);

uint8_t records[7];
uint8_t buf[64];

#define Forward     (0)
#define Backward    (1)
#define Left        (2)
#define Right       (3)
#define Stop_       (4)
#define Room        (5)
#define one         (6)
#define two         (7)

void setup() {
  nh.initNode();
  nh.advertise(chatter);
  broadcaster.init(nh);

  myVR.begin(9600);
  Serial.begin(57600);
}

void loop() {

  // Voice recognition
  int ret;
  ret = myVR.recognize(buf, 50);
  if (ret > 0) {
    char voice[30];
    switch (buf[1]) {
      case Forward:
        strcpy(voice,"Forward");
        Serial.println(voice);
```

```
      break;
    case Backward:
      strcpy(voice,"Backward");
      Serial.println(voice);
      break;
    case Left:
      strcpy(voice,"Left");
      Serial.println(voice);
      break;
    case Right:
      strcpy(voice,"Right");
      Serial.println(voice);
      break;
    case Stop_:
      strcpy(voice,"Stop");
      Serial.println(voice);
      break;
    case Room:
      strcpy(voice,"Room");
      Serial.println(voice);
      break;
    case one:
      strcpy(voice,"one");
      Serial.println(voice);
      break;
    case two:
      strcpy(voice,"two");
      Serial.println(voice);
      break;
    default:
      strcpy(voice,"Record function undefined");
      Serial.println("Record function undefined");
      break;
  }
  str_msg.data = voice;
  chatter.publish(&str_msg);
}
```

```
  nh.spinOnce();
}
```

Python Codes for Voice Commands in ROS

```python
#! /usr/bin/env python3

import rospy
import actionlib
from move_base_msgs.msg import MoveBaseAction, MoveBaseGoal
from geometry_msgs.msg import Twist
from std_msgs.msg import String
from queue import Queue

class GoalSender:
    def __init__(self):
        self.navclient = actionlib.SimpleActionClient('move_base', MoveBaseAction)
        self.navclient.wait_for_server()

        self.destination_queue = Queue()
        self.current_goal = None

        rospy.Subscriber("chatter", String, self.goal_callback)

        self.pub = rospy.Publisher('cmd_vel', Twist, queue_size=10

    def goal_callback(self, data):
        command = data.data.lower()
        self.command = data.data
        print(self.command)

        if command == "stop":
            self.send_twist(0, 0)
            self.navclient.cancel_all_goals()
            self.destination_queue = Queue()
            self.current_goal = None
            return

        if self.current_goal is not None:
            return

        if "forward" in command:
            self.send_twist(0.5, 0)
        elif "backward" in command:
            self.send_twist(-0.5, 0)
        elif "left" in command:
            self.send_twist(0, 0.5)
```

```
        elif "right" in command:
            self.send_twist(0, -0.5)
        else:
            destination = command
            self.destination_queue.put(destination)
            self.send_next_goal()

    def send_twist(self, linear_x, angular_z):
        twist = Twist()
        twist.linear.x = linear_x
        twist.angular.z = angular_z
        self.pub.publish(twist)

    def send_next_goal(self):
        if not self.destination_queue.empty():
            destination = self.destination_queue.get()
            goal = self.create_goal(destination)
            self.current_goal = goal
            self.navclient.send_goal(goal, done_cb=self.goal_done_callback)

    def create_goal(self, destination):
        goal = MoveBaseGoal()
        goal.target_pose.header.frame_id = "map"
        goal.target_pose.header.stamp = rospy.Time.now()

        if "one" in destination:
            goal.target_pose.pose.position.x = -1.1533409357070923#0.5667285919189453
            goal.target_pose.pose.position.y = 0.2259044647216797#-1.8380910158157349
            goal.target_pose.pose.position.z = 0.004180908203125#0.0009326934814453125
            #goal.target_pose.pose.orientation.z = -0.05922655589870491
            goal.target_pose.pose.orientation.w = 1.0

        elif "two" in destination:
            goal.target_pose.pose.position.x = 0.9408702850341797#0.7278060913085938
            goal.target_pose.pose.position.y = -1.3327442407608032#1.2667226791381836
            goal.target_pose.pose.position.z = 
0.000408172607421875#0.0038661956787109375
            #goal.target_pose.pose.orientation.z = 0.06044137556277906
            goal.target_pose.pose.orientation.w = 1.0
```

```
        return goal

    def goal_done_callback(self, state, result):
        self.current_goal = None
        self.send_next_goal()

if __name__ == '__main__':
    rospy.init_node('combined_node')
    goal_sender = GoalSender()
    rospy.spin()
```

OBSTACLE AVOIDANCE

Arduino Codes for Sending Ultrasonic Data to ROS

```
#include <SoftwareSerial.h>
#include <ros.h>
#include <std_msgs/Float32.h>
#include <sensor_msgs/Range.h>
#include <ros/time.h>
#include <tf/transform_broadcaster.h>

ros::NodeHandle nh;

#define TrigA A2
#define EchoA A3
#define TrigB A6
#define EchoB A7

sensor_msgs::Range sonar_ranges[2];
ros::Publisher sonar_ranges_pub_a("/sonar_ranges_a", &sonar_ranges[0]);
ros::Publisher sonar_ranges_pub_b("/sonar_ranges_b", &sonar_ranges[1]);

geometry_msgs::TransformStamped t[2];
tf::TransformBroadcaster broadcaster;

char base_link[] = "/base_link";
char sonar_front[] = "/sonar_front";
char sonar_back[] = "/sonar_back";

float getDistance(int trigPin, int echoPin) {
  long duration, distance;
  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);
  duration = pulseIn(echoPin, HIGH);
  distance = (duration/2) / 29.1;
  return distance;
}
```

```
void setup() {
  nh.initNode();
  nh.advertise(sonar_ranges_pub_a);
  nh.advertise(sonar_ranges_pub_b);
  broadcaster.init(nh);

  myVR.begin(9600);
  Serial.begin(57600);

  pinMode(TrigA, OUTPUT);
  pinMode(EchoA, INPUT);
  pinMode(TrigB, OUTPUT);
  pinMode(EchoB, INPUT);
}

void loop() {
  ros::Time current_time = nh.now();

  // Ultrasonic Sensor A
  float distance_a = getDistance(TrigA, EchoA);
  sonar_ranges[0].range = distance_a / 100;
  sonar_ranges[0].header.stamp = current_time;
  sonar_ranges[0].header.frame_id = sonar_front;
  sonar_ranges_pub_a.publish(&sonar_ranges[0]);

  t[0].header.frame_id = base_link;
  t[0].child_frame_id = sonar_front;
  t[0].header.stamp = current_time;
  t[0].transform.translation.x = 0.18;
  t[0].transform.translation.y = 0.28;
  t[0].transform.translation.z = 0.14;
  t[0].transform.rotation.x = 0.0;
  t[0].transform.rotation.y = 0.0;
  t[0].transform.rotation.z = 0.0;
  t[0].transform.rotation.w = 1.0;
  broadcaster.sendTransform(t[0]);

  // Ultrasonic Sensor B
  float distance_b = getDistance(TrigB, EchoB);
  sonar_ranges[1].range = distance_b / 100;
```

```
  sonar_ranges[1].header.stamp = current_time;
  sonar_ranges[1].header.frame_id = sonar_back;
  sonar_ranges_pub_b.publish(&sonar_ranges[1]);

  t[1].header.frame_id = base_link;
  t[1].child_frame_id = sonar_back;
  t[1].header.stamp = current_time;
  t[1].transform.translation.x = -0.1;
  t[1].transform.translation.y = 0.0;
  t[1].transform.translation.z = 0.0;
  t[1].transform.rotation.x = 0.0;
  t[1].transform.rotation.y = 0.0;
  t[1].transform.rotation.z = 0.0;
  t[1].transform.rotation.w = 1.0;
  broadcaster.sendTransform(t[1]);

  nh.spinOnce();
}
```

ROS HectorSLAM Configuration

```
<!-- Hector SLAM -->
<arg name="tf_map_scanmatch_transform_frame_name"
default="scanmatcher_frame"/>
<arg name="base_frame" default="base_link"/>
<arg name="odom_frame" default="base_link"/>

<arg name="pub_map_odom_transform" default="false"/>
<arg name="scan_subscriber_queue_size" default="5"/>
<arg name="scan_topic" default="scan"/>
<arg name="map_size" default="2048"/>
<arg name="pub_odometry" default="true"/>

<node pkg="hector_mapping" type="hector_mapping" name="hector_mapping"
output="screen">
  <param name="pub_odometry" value="$(arg pub_odometry)"/>

  <!-- Frame names -->
  <remap from="map" to="mapcurrent" />
  <param name="map_frame" value="mapcurrent_frame" />
  <param name="base_frame" value="$(arg base_frame)" />
  <param name="odom_frame" value="$(arg odom_frame)" />

  <!-- Tf use -->
  <param name="use_tf_scan_transformation" value="true"/>
  <param name="use_tf_pose_start_estimate" value="false"/>
  <param name="pub_map_odom_transform" value="$(arg
pub_map_odom_transform)"/>

  <!-- Map size / start point -->
  <param name="map_resolution" value="0.050"/>
  <param name="map_size" value="$(arg map_size)"/>
  <param name="map_start_x" value="0.5"/>
  <param name="map_start_y" value="0.5" />
  <param name="map_multi_res_levels" value="2" />

  <!-- Map update parameters -->
  <param name="update_factor_free" value="0.4"/>
```

```
    <param name="update_factor_occupied" value="0.9" />
    <param name="map_update_distance_thresh" value="0.4"/>
    <param name="map_update_angle_thresh" value="0.06" />
    <param name="laser_z_min_value" value = "-1.0" />
    <param name="laser_z_max_value" value = "1.0" />

    <!-- Advertising config -->
    <param name="advertise_map_service" value="true"/>

    <param name="scan_subscriber_queue_size" value="$(arg
scan_subscriber_queue_size)"/>
    <param name="scan_topic" value="$(arg scan_topic)"/>
    <param name="tf_map_scanmatch_transform_frame_name" value="$(arg
tf_map_scanmatch_transform_frame_name)" />
</node>

<node pkg="tf" type="static_transform_publisher" name="link_to_laser_bc" args="0.2
0.28 0 0 0 0 base_link laser 100" />
```

AMCL Localization Configuration

```
<!--AMCL-->
<node pkg="amcl" type="amcl" name="amcl">
    <param name="tf_broadcast" value="true" />
    <param name="base_frame_id" value="/base_link" />
    <param name="global_frame_id" value="map" />
    <param name="odom_frame_id" value="scanmatch_odom" />
    <param name="use_map_topic" value="false" />

    <remap from="scan" to="scan" />
    <param name="odom_model_type" value="diff" />
    <param name="transform_tolerance" value="0.2" />
    <param name="gui_publish_rate" value="-1.0"/>
    <param name="laser_max_beams" value="200"/>
    <param name="laser_max_range" value="12"/>
    <param name="min_particles" value="30"/>
    <param name="max_particles" value="70"/>
    <param name="update_min_d" value="0.01"/>
    <param name="kld_err" value="0.01"/>
    <param name="kld_z" value="0.99"/>
    <param name="odom_alpha1" value="0.2"/>
```

```
    <param name="odom_alpha2" value="0.2"/>
    <param name="odom_alpha3" value="0.2"/>
    <param name="odom_alpha4" value="0.2"/>
    <param name="odom_alpha5" value="0.2"/>
    <param name="laser_z_hit" value="0.95"/>
    <param name="laser_z_short" value="0.1"/>
    <param name="laser_z_max" value="0.05"/>
    <param name="laser_z_rand" value="0.05"/>
    <param name="laser_sigma_hit" value="0.2"/>
    <param name="laser_lambda_short" value="0.1"/>
    <param name="laser_model_type" value="likelihood_field"/>
    <param name="laser_likelihood_max_dist" value="2.0"/>
    <param name="update_min_a" value="0.1"/>
    <param name="resample_interval" value="2"/>
    <param name="transform_tolerance" value="1.0"/>
    <param name="recovery_alpha_slow" value="0.0"/>
    <param name="recovery_alpha_fast" value="0.0"/>
</node>
```

Move Base Parameters

```
<!--move_base-->
<arg name="base_global_planner" default="navfn/NavfnROS"/>
<arg name="base_local_planner" default="dwa_local_planner/DWAPlannerROS"/>

<node pkg="move_base" type="move_base" respawn="false" name="move_base"
output="screen">

    <param name="base_global_planner" value="$(arg base_global_planner)"/>
    <param name="base_local_planner" value="$(arg base_local_planner)"/>

    <rosparam file="$(find chairlidar)/param/base_local_planner_params.yaml"
command="load" />

    <rosparam file="$(find chairlidar)/param/costmap_common_params.yaml"
command="load" ns="global_costmap" />
    <rosparam file="$(find chairlidar)/param/costmap_common_params.yaml"
command="load" ns="local_costmap" />

    <rosparam file="$(find chairlidar)/param/local_costmap_params.yaml"
command="load" ns="local_costmap" />
```

```
    <rosparam file="$(find chairlidar)/param/global_costmap_params.yaml"
command="load" ns="global_costmap" />

</node>
```

Base Local Planner Parameters

```
controller_frequency: 3.0
recovery_behavior_enabled: true
conservative_reset_dist: 0.2

NavfnROS:
  allow_unknown: true
  default_tolerance: 0.1

DWAPlannerROS:
  # Robot configuration parameters
  acc_lim_x: 2.5
  acc_lim_y: 0.0
  acc_lim_th: 3.2

  max_vel_x: 0.5
  min_vel_x: -0.5
  max_vel_y: 0.0
  min_vel_y: 0.0

  max_vel_trans: 0.5
  min_vel_trans: 0.5
  max_vel_theta: 0.5
  min_vel_theta: 0.3

  max_trans_vel: 0.55
  min_trans_vel: 0.1
  max_rot_vel: 0.5
  min_rot_vel: 0.3

  yaw_goal_tolerance: 3.0
  xy_goal_tolerance: 0.5
  latch_xy_goal_tolerance: false

  holonomic_robot: false
```

```
  sim_time: 0.8
  occdist_scale: 10
  meter_scoring: false
```

Local Costmap Parameters

```
global_frame: scanmatch_odom
rolling_window: true
width: 1.5
height: 1.5
update_frequency: 1.0
publish_frequency: 5.0
transform tolerance: 0.5
static_map: false

plugins:
  - {name: obstacles_laser,           type: "costmap_2d::ObstacleLayer"}
  - {name: inflation_l,               type: "costmap_2d::InflationLayer"}
```

Global Costmap Parameters

```
global_frame: map
rolling_window: false
track_unknown_space: true
update_frequency: 1.0
publish_frequency: 0.5
transform_tolerance: 0.5

static_map: true

plugins:
  - {name: static,                  type: "costmap_2d::StaticLayer"}
  - {name: inflation_g,             type: "costmap_2d::InflationLayer"}
```

Common Costmap Parameters

```
footprint: [[-0.35, -0.4], [-0.35, 0.4], [0.35, 0.4], [0.35, -0.4]]
footprint_padding: 0.01

robot_base_frame: base_link
update_frequency: 2.0
```

```
publish_frequency: 1.0
transform_tolerance: 0.3

resolution: 0.1

obstacle_range: 1
raytrace_range: 1.2

#layer definitions
static:
  map_topic: /map
  subscribe_to_updates: true

obstacles_sensor:
  observation_sources: laser_scan_sensor ultrasonic_a ultrasonic_b
  laser_scan_sensor: {data_type: LaserScan, clearing: true, marking: true, topic: scan, inf_is_valid: true}
  ultrasonic_a: {data_type: Range, clearing: true, marking: true, topic: /sonar_ranges_a, min_range: 0.1, max_range: 1.2, inf_is_valid: true}
  ultrasonic_b: {data_type: Range, clearing: true, marking: true, topic: /sonar_ranges_b, min_range: 0.1, max_range: 1.2, inf_is_valid: true}

inflation_g:
  inflation_radius: 0.2

inflation_l:
  inflation_radius: 0.2
```

MOTOR DRIVER

Arduino Codes for Motor Control

```
#include <Arduino.h>
#include <ros.h>
#include <geometry_msgs/Twist.h>
#include <std_msgs/Int16.h>

#define LeftRPWM 2
#define LeftLPWM 9
#define RightRPWM 7
#define RightLPWM 6
#define PWML 3
#define PWMR 10

int value1 = digitalRead(RightRPWM);
int value2 = digitalRead(RightLPWM);
int value3 = digitalRead(LeftRPWM);
int value4 = digitalRead(LeftLPWM);
int value5 = digitalRead(PWML);
int value6 = digitalRead(PWMR);

// Default_speed.
const int default_vel = 150;

ros::NodeHandle node;
geometry_msgs::Twist msg;

//stop
void motor_stop()
{
  if ((value1 = HIGH) || (value3 = HIGH) || (value2 = HIGH) || (value4 = HIGH)){
    for (int speed = 40; speed >= 0; speed-=10) {
      analogWrite(PWML, speed); // control the speed
      analogWrite(PWMR, speed);
      delay(20);
    }
    digitalWrite (LeftLPWM, LOW);
    digitalWrite (LeftRPWM, LOW);
    digitalWrite (RightLPWM, LOW);
```

```
    digitalWrite (RightRPWM, LOW);
  }

  else if ((value1 = LOW) && (value3 = LOW) && (value2 = LOW) && (value4 =
LOW)){
    digitalWrite (LeftLPWM, LOW);
    digitalWrite (LeftRPWM, LOW);
    digitalWrite (RightLPWM, LOW);
    digitalWrite (RightRPWM, LOW);
    delay(20);
    }
  Serial.println ("MOTOR STOPS");
}

void roverCallBack(const geometry_msgs::Twist & msg)
{
  const float x = msg.linear.x;
  const float z_rotation = msg.angular.z;

  float left_cmd = (-z_rotation*0.1)/2.0 + x;
  float right_cmd = 2.0*x - left_cmd;

  int right_write = int( default_vel * right_cmd);
  int left_write = int( default_vel * left_cmd );

  int speedl = abs(left_write);
  int speedr = abs(right_write);

  int abs_left_write =  abs(left_write);
  int abs_right_write = abs(right_write);

  if(msg.linear.x > 0 && msg.angular.z == 0) //forward
  {
    digitalWrite (LeftLPWM, HIGH);
    digitalWrite (LeftRPWM, LOW);
    digitalWrite (RightLPWM, LOW);
    digitalWrite (RightRPWM, HIGH);

    int speed = 0;
    while(speed <= abs_right_write || speed <= abs_left_write) {
```

```
    if (speed <= abs_right_write) {
      analogWrite(PWMR, speed); // control the speed of the right wheel
    }
    if (speed <= abs_left_write) {
      analogWrite(PWML, speed); // control the speed of the left wheel
    }
    delay(10);
    speed+=10;
  }

}
else
{
  if(msg.linear.x == 0 && msg.angular.z > 0) //left
  {
    digitalWrite (LeftLPWM, LOW);
    digitalWrite (LeftRPWM, HIGH);
    digitalWrite (RightLPWM, LOW);
    digitalWrite (RightRPWM, HIGH);

    int speed = 0;
    while(speed <= abs_right_write) {
      if (speed <= abs_right_write) {
        analogWrite(PWMR, speed+70); // control the speed of the right wheel
        analogWrite(PWML, speed+70);
      }
      delay(10);
      speed+=10;
    }
  }
  else
  {
    if(msg.linear.x == 0 && msg.angular.z == 0) //stop
    {
      motor_stop();
    }
    else
    {
      if(msg.linear.x == 0 && msg.angular.z < 0) //right
      {
```

```
  digitalWrite (LeftLPWM, HIGH);
  digitalWrite (LeftRPWM, LOW);
  digitalWrite (RightLPWM, HIGH);
  digitalWrite (RightRPWM, LOW);

  int speed = 0;
  while(speed <= abs_left_write) {
   if (speed <= abs_left_write) {
     analogWrite(PWML, speed+70); // control the speed of the right wheel
     analogWrite(PWMR, speed+70); //80
   }
   delay(10);
   speed+=10;
  }
}
else
{
  if(msg.linear.x > 0 && msg.angular.z < 0) //forwardright
  {
   digitalWrite (LeftLPWM, HIGH);
   digitalWrite (LeftRPWM, LOW);
   digitalWrite (RightLPWM, LOW);
   digitalWrite (RightRPWM, HIGH);

   int speed = 0;
   while(speed <= abs_right_write || speed <= abs_left_write) {
     if (speed <= abs_right_write) {
       analogWrite(PWMR, speed); // control the speed of the right wheel
     }
     if (speed <= abs_left_write) {
       analogWrite(PWML, speed); // control the speed of the left wheel
     }
     delay(10);
     speed+=10;
   }
  }
  else
  {
   if(msg.linear.x > 0 && msg.angular.z > 0) //forwardleft
   {
```

```
  digitalWrite (LeftLPWM, HIGH);
  digitalWrite (LeftRPWM, LOW);
  digitalWrite (RightLPWM, LOW);
  digitalWrite (RightRPWM, HIGH);

  int speed = 0;
  while(speed <= abs_right_write || speed <= abs_left_write) {
    if (speed <= abs_right_write) {
      analogWrite(PWMR, speed); // control the speed of the right wheel
    }
    if (speed <= abs_left_write) {
      analogWrite(PWML, speed); // control the speed of the left wheel
    }
    delay(10);
    speed+=10;
  }
}
else
{
  if(msg.linear.x < 0 && msg.angular.z < 0) //backwardright
  {
    digitalWrite (LeftLPWM, LOW);
    digitalWrite (LeftRPWM, HIGH);
    digitalWrite (RightLPWM, HIGH);
    digitalWrite (RightRPWM, LOW);

    int speed = 0;
    while(speed <= abs_right_write || speed <= abs_left_write) {
      if (speed <= abs_right_write) {
        analogWrite(PWMR, speed); // control the speed of the right wheel
      }
      if (speed <= abs_left_write) {
        analogWrite(PWML, speed); // control the speed of the left wheel
      }
      delay(10);
      speed+=10;
    }
  }
  else
  {
```

```
if(msg.linear.x < 0 && msg.angular.z > 0) //backwardleft
{
  digitalWrite (LeftLPWM, LOW);
  digitalWrite (LeftRPWM, HIGH);
  digitalWrite (RightLPWM, HIGH);
  digitalWrite (RightRPWM, LOW);

  int speed = 0;
  while(speed <= abs_right_write || speed <= abs_left_write) {
    if (speed <= abs_right_write) {
      analogWrite(PWMR, speed); // control the speed of the right wheel
    }
    if (speed <= abs_left_write) {
      analogWrite(PWML, speed); // control the speed of the left wheel
    }
    delay(10);
    speed+=10;
  }
}
else
{
  if(msg.linear.x < 0 && msg.angular.z == 0) //backward
  {
    digitalWrite (LeftLPWM, LOW);
    digitalWrite (LeftRPWM, HIGH);
    digitalWrite (RightLPWM, HIGH);
    digitalWrite (RightRPWM, LOW);

    int speed = 0;
    while(speed <= abs_right_write || speed <= abs_left_write) {
      if (speed <= abs_right_write) {
        analogWrite(PWMR, speed); // control the speed of the right wheel
      }
      if (speed <= abs_left_write) {
        analogWrite(PWML, speed); // control the speed of the left wheel
      }
      delay(10);
      speed+=10;
    }
  }
```

```
         else //stop
         {
          motor_stop();
         }
        }
       }
      }
     }
    }
   }
  }
 }
}

ros::Subscriber <geometry_msgs::Twist> sub("cmd_vel", roverCallBack);

// the setup function
void setup()
{
 Serial.begin(57600);

 node.initNode();
 node.subscribe(sub);

 Serial.println ("START");
 pinMode (LeftRPWM, OUTPUT);
 pinMode (LeftLPWM, OUTPUT);
 pinMode (RightRPWM, OUTPUT);
 pinMode (RightLPWM, OUTPUT);
 pinMode (PWML, OUTPUT);
 pinMode (PWMR, OUTPUT);
}

void loop()
{
 node.spinOnce();
 delay(1);
}
```

Annex IV

Bill of Materials

Item #	Item Description	Specifications	Vendor /Seller	Qty	Unit	Unit Cost	Total Cost
1	Raspberry Pi 4B	Power supply output voltage: 5.1 V Input voltage: Between 96 and 264 Vac Frequency: 50/60 Hz ±3 Hz Rated current: 3 A Maximum power: 15.3 W Minimum efficiency: 81% Ripple: 120mVp-p Protections: Short-circuit, overcurrent, and overheating Cable: 18 AWG 1.5 m with USB-C output connector	Facebook Marketplace	1	pc	₱6,500.00	₱6,500.00
2	Micro-SD Card	64GB	PC Express	1	pc	₱390.00	₱390.00
3	RPLiDAR A1	Model: RPLIDAR A1M8-R6 Distance Range: A1M8-R4 and the belowing models 0.15 - 6 m A1M8-R5 0.15-12m Angular Range: 0-360 degree Distance Resolution: ＜ 0.5mm ＜ 1% of the distance (All distance range) Angular Resolution: ≤1 degree Sample Duration: 0.125 millisecond Sample Frequency: ≥ 8000Hz Scan Rate: 5.5Hz Weight: 170g	DFRobot *https://www.dfrobot.com/product-1125.html*	1	pc	₱6,900.00	₱6,900.00
4	Arduino Mega 2560 R3	Microcontroller: ATmega2560 Operating Voltage: 5V	Shopee *Makerlab Electronics*	1	pc	₱850.00	₱850.00

		Input Voltage (recommended): 7-12V (clone boards until 9V only) Input Voltage (limit): 6-20V Digital I/O Pins: 54 (of which 15 provide PWM output) Analog Input Pins: 16 DC Current per I/O Pin: 20 mA DC Current for 3.3V Pin: 50 mA Flash Memory: 256 KB of which 8 KB used by bootloader SRAM: 8 KB EEPROM: 4 KB Clock Speed: 16 MHz	https://shp.ee/cbff7ut				
5	Arduino Uno R3	Microcontroller: ATmega328 Operating Voltage: 5V Input Voltage (recommended): 7-9V Digital I/O Pins: 14 (of which 6 provide PWM output) Analog Input Pins: 6 DC Current per I/O Pin: 40 mA DC Current for 3.3V Pin: 50 mA Flash Memory:32 KB (ATmega328) of which 0.5 KB used by the bootloader SRAM: 2 KB (ATmega328) EEPROM: 1 KB (ATmega328) Clock Speed: 16 MHz	Shopee *Makerlab Electronics* https://shp.ee/zqi5uyn	1	pc	₱549.00	₱549.00
6	Voice Recognition Module V3	Voltage: 4.5-5.5V Current: <40mA Digital Interface: 5V TTL level for UART interface and GPIO	Shopee *Makerlab Electronics* https://shp.ee/ve6ydb4	1	pc	₱1,750.00	₱1,750.00

		Analog Interface: 3.5mm mono-channel microphone connector + microphone pin interface Size: 31mm x 50mm Recognition accuracy: 99% (under ideal environment)					
7	Ultrasonic Sensor	Power Supply: DC 5V. Working Current: 15mA. Working Frequency: 40Hz. Ranging Distance : 2cm – 400cm/4m. Resolution : 0.3 cm. Measuring Angle: 15 degree. Trigger Input Pulse width: 10uS. Dimension: 45mm x 20mm x 15mm.	Shopee *Makerlab Electronics* https://shp.ee/wk2qzwh	2	pcs	₱49.00	₱98.00
8	BTS 7960 Motor Driver	Input voltage: 6V-27V Model: IBT-2 Maximum current: 43A Input level: 3.3-5V Control mode: PWM or level Duty cycle: 0-100%	Shopee *Makerlab Electronics* https://shp.ee/uwtspvi	2	pcs	₱305.00	₱610.00
9	Waveshare 7inch HDMI LCD w/ case	Size: 7" Resolution: 1024×600 Display Interface: HDMI / VGA Display Panel: IPS Viewing Angle: 170° Touch Type: Capacitive Touch Points: 5-point Touch Port: USB	Shopee *Makerlab Electronics* https://shp.ee/ecarq4k	1	pc	₱3,600.00	₱3,600.00
10	LM2596S Buck Converter	Input Voltage: 3 to 40 V Output Voltage Range: 1.23 to 37 V Max Output Current: 3 A Adjustment: 25-Turn Trimpot Efficiency: up to ~93% Switching Frequency: 150	Shopee *Makerlab Electronics* https://shp.ee/5xh5vzq	1	pc	₱45.00	₱45.00

		kHz Built-In Protection: thermal shutdown and current limit					
11	External Mic (Lapel)	Length: About 1.50 m Connector: 3.5mm plug (100cm braided wire) Polar pattern: Omni-directional Frequency range: 100-16kHz Operating voltage: 2.0V	Shopee *Powermax PH* https://shp.ee/zr6a49w	1	pc	₱20.00	₱20.00
12	Wheelchair	Seat width :47cm Seat height :48cm Seat depth :41cm Bearing :100Kg Net weight :11Kg Solid front wheel: 6inches Solid rear wheel: 16/20 inches Product features: foldable List of accessories: instructions, leg straps, belts	Shopee *Helcare* https://shp.ee/iyv2t5d	1	pc	₱2,809.00	₱2,809.00
13	DC Motor	Voltage: 24VDC Rated Current: 14A Rate Speed: 2800 RPM Output: 250W	Lazada	2	pcs	₱2,433.00	₱4,866.00
14	12V Lead Acid Battery	Brand: Masashi Voltage: 12V Battery Capacity: 22Ah Battery Type: Lead Acid	Pacific Electronics 653-655 Puyat St., Zone 030, Brgy. 309, Quiapo, Manila	2	pcs	₱1,700.00	₱3,400.00
15	Battery Charger	Input Voltage: 187 - 253V AC-50 Hz Powery: 50 -360W		1	pc	₱980.00	₱980.00
16	Adapter (DC Socket)	N/A		1	pc	₱180.00	₱180.00
17	Fuse	Current: 30 A Size: 5 mm x 20 mm	Ohms Electronics Center	1	pc	₱5.00	₱5.00
18	Fuse Holder	Type: With Panel Mount Fit: by 5 x 20mm Fuses		1	pc	₱5.00	₱5.00

		Nominal Voltage: AC 10A 250VAC Thread Support Diameter 12mm / 0.47 inch Designed with glass tube, 5x20mm dimension, overload and over current protection. Total Size: 38 mm x 16mm / 1.5" x 0.63" (Length X Diameter) Material: Plastic, Metal	National Hwy, 4023 San Pedro, Laguna				
19	15A Toggle Switch	Current rating: 15A Voltage rating: Up to 250V AC or DC Switch type: Single-Pole Single-Throw (SPST) Material: Metal Pins: 2 pins		1	pc	₱60.00	₱60.00
20	Raspberry Pi 4 Case with Cooling Fan	N/A	Shopee *circuitrocks* https://shp.ee/vhm4g8h	1	pc	₱135.00	₱135.00
21	Arduino UNO R3 Case	Dimensions: 80mm x 65mm Material: Acrylic	Shopee *Makerlab Electronics* https://shp.ee/qtbtdgw	1	pc	₱50.00	₱50.00
22	Weatherproof Enclosure	Dimensions: 222mm x 146mm x 81mm Material: ABS (Acrylonitrile Butadiene Styrene) plastic IP Rating: IP65 NEMA Rating: NEMA 4 and 4X	Makerlab Electronics 1231 Tomas Mapua St, Santa Cruz, Manila, 1003 Metro Manila	1	pc	₱500.00	₱500.00
23	Weatherproof Enclosure	Dimensions: 83mm x 58mm x 33mm Material: ABS (Acrylonitrile Butadiene Styrene) plastic IP Rating: IP65 NEMA Rating: NEMA 4 and 4X		1	pc	₱85.00	₱85.00

24	Ultrasonic Sensor Case	N/A	Shopee *MakerForge* https://shp.ee/mq3ndwa	2	pc	₱66.00	₱132.00
25	eSUN Silk PLA Filament	Diamter: 1.75mm Color: Silk Blue Weight: 1kg	Makerlab Electronics 1231 Tomas Mapua St, Santa Cruz, Manila, 1003 Metro Manila	215	grams	₱0.75	₱162.00
26	Heatsink	Material: Aluminum Color: Gold Dimensions: 1 x large heat sink (14 x 14 x 6mm) 1 x medium heat sink (14 x 10 x 6mm) 2 x small heat sink (9 x 9 x 5mm)	Shopee *circuitrocks* https://shp.ee/jiqys5t	1	pack	₱44.00	₱44.00
27	Heatsink	Material: Aluminum Color: Silver Dimension: 1 x large heat sink (6 x 14 x 14mm) 2 x small heat sink (5 x 9 x 9mm)	Makerlab Electronics 1231 Tomas Mapua St, Santa Cruz, Manila, 1003 Metro Manila	1	pc	₱20.00	₱20.00
28	USB Type-C	Length: About 50cm Cable Color: Black		1	pc	₱49.00	₱49.00
29	Micro USB Cable (2m)	Length: 2 meters Maxmimum Current: 2.4A	Robinsons Galleria South, San Pedro, Laguna	1	pc	₱200.00	₱200.00
30	Y Splitter	Color: Yellow Connector Gender: Male-to-Female Shape: Round	V.SY Electronics Center V. SY Electronics Bldg. National Highway 1674, Barangay Dita Rd, Santa Rosa, Laguna	2	pcs	₱150.00	₱300.00

31	T60 Connector	Female Internal Diameter: About 3.5mm / 0.14" Female Connector Length: About 12mm / 0.47" Male Internal Diameter: About 4mm / 0.16" Male Connector Length: About 12mm / 0.47"	Facebook Marketplace	5	pcs	₱48.00	₱240.00
32	T90 Connector	Metal connector size: 4.5mm Body Material: Gold-plated copper Internal Material: Nylon/PA Color: Yellow Weight: 30g	DEECO 607 Sales St., Quiapo, Manila	1	pc	₱45.00	₱45.00
33	22 AWG Red	Wire Type: Stranded Wire Length: 3m Cable Color: Red		3	meters	₱4.00	₱12.00
34	22 AWG Gray	Wire Type: Stranded Wire Length: 3m Cable Color: Gray		3	meters	₱4.00	₱12.00
35	22 AWG Blue	Wire Type: Stranded Wire Length:1m Cable Color: Blue		1	meter	₱4.00	₱4.00
36	22 AWG Yellow	Wire Type: Stranded Wire Length: 4m Cable Color: Yellow		4	meters	₱4.00	₱16.00
37	22 AWG White	Wire Type: Stranded Wire Length: 4m Cable Color: White		4	meters	₱4.00	₱16.00
38	18 AWG Green	Wire Type: Stranded Wire		2	meters	₱8.00	₱16.00

		Length: 2m Cable Color: Green					
39	Speaker Wire	Wire Type: Stranded Wire Length: 1m Cable Color: Black & Red		1	meter	₱16.00	₱16.00
40	16 AWG Speaker Wire	Wire Type: Stranded Wire Length: 3m Cable Color: Red		1	meter	₱30.00	₱30.00
41	22 AWG White	Wire Type: Solid Wire Length: 2m Cable Color: White		2	meters	₱5.00	₱10.00
42	Battery Terminal Lug	Size: 35mm x 8mm		1	pack	₱65.00	₱65.00
43	2.5 Heat Shrink	Diameter: 2.5"		1	pack	₱44.00	₱44.00
44	3.5 Heat Shrink	Diameter: 3.5"		1	pack	₱32.00	₱32.00
45	5.0 Heat Shrink	Diameter: 5.0"		1	pack	₱18.00	₱18.00
46	30 cm Male-to-Female DuPont Wire	Wire Length: 30cm Wire Type: Male-to-Female	Student Corner Zobel St., Ermita, Manila	4	pcs	₱6.00	₱24.00
47	Sprocket	Teeth: 24	Namata Cycle Center #35 6th St., Pacita Ave., Pacita Complex 1, San Pedro, Laguna	2	pcs	₱120.00	₱240.00
48	Chains	Type: Road Bike Chain		1	pc	₱150.00	₱150.00
49	Bolts	Size: 3"	Wil-Wide Hardware San Vicente 55 Pacita Ave., Ph1 Pacita Complex 1 Laguna	6	pcs	₱14.00	₱84.00
50	Bolts	Size: 2.5"		8	pcs	₱13.00	₱104.00
51	Bolts	Size: 1.7”		4	pcs	₱3.00	₱12.00
52	Bolts & Nuts	Size: 5/16x4		1	pack	₱112.00	₱148.00
53	Nuts	N/A		14	pcs	₱3.00	₱42.00
54	Washer	Size: 2”		4	pcs	₱14.00	₱56.00
55	Washer	Size: 5/16x4"		6	pcs	₱11.00	₱66.00
56	Screws	Size: 2cm		14	pcs	₱3.57	₱50.00
56	Soundproof Foam	Brand: OEM Material: Foam	Lazada *Martial Arts* https://s.lazada	12	pcs	₱346.00	₱346.00

		Dimension: 11.8" x 11.8" x 1" Color: Black	.com.ph/s.ShTZf				
57	Gray Spray Paint	Brand: Nikko Color: Gray	Triple M Enterpises Dulo San Vicente 4023 San Pedro Laguna	1	pc	₱110.00	₱110.00
58	Black Spray Paint	Brand: Bosny Color: Black	DEECO 607 Sales St., Quiapo, Manila	1	pc	₱110.00	₱110.00
59	Cable Tie	Length: 4" Color: Blue		1	pack	₱48.00	₱48.00
60	Fastening tape	Brand: Polar Bear Size: 18mm x 0.46m	ACE Hardware Ground Floor, Harmony Village Mall, Olympia St, San Pedro, 4023 Laguna	1	pc	₱100.00	₱100.00
61	Mounting Tape	Brand: Polar Bear Size: 24mm x 1m		1	pc	₱90.00	₱90.00
					TOTAL AMOUNT	**₱37,650.00**	

Annex V

Evaluation Forms

Technological University of the Philippines
Ayala Blvd., Ermita, Manila
College of Engineering
Electronics Engineering Department

Expert Evaluation Form (Based on ISO/IEC 25010)

Project Title: **ChairLiDAR: LiDAR-Based Voice-Controlled Wheelchair with Indoor Auto-Navigation System Using SLAM Algorithm for Quadriplegic Patients**

Name: **Engr. Hanna Ardan, RMEE** Age: **25 years old** Sex: **Female**
Date Administered: **April 25, 2023** Time: **1:00 - 3:00 PM** Administered by:
Name of the Company:
Address: **Block 11, Lot 33, Brighton Phase 4, Lancaster, Pasong Camachile 1, General Trias, Cavite**
Designation: Department:

Direction:
Please indicate a check mark (✔) under the column that best describes your responses for each item about the ChairLiDAR: LiDAR-Based Voice-Controlled Wheelchair with Indoor Auto-Navigation System Using SLAM Algorithm for Quadriplegic Patients. The rating scale is given below:

Numerical Rating	Equivalent
5	Excellent
4	Very Good
3	Good
2	Fair
1	Poor

INDICATORS	5	4	3	2	1
A. Functional Suitability					
1. **Functional completeness -** Degree to which the set of functions covers all the specified tasks and user objectives.	✓				
2. **Functional correctness -** Degree to which a product or system provides the correct results		✓			

with the needed degree of precision.					
3. **Operability -** Degree to which a product or system has attributes that make it easy to operate and control.jectives.		✓			
B. Performance Efficiency					
1. **Time behavior -** Degree to which the response and processing times and throughput rates of a product or system, when performing its functions, meet requirements.		✓			
2. **Resource utilization -** Degree to which the amounts and types of resources used by a product or system, when performing its functions, meet requirements.	✓				
3. **Capacity -** Degree to which the maximum limits of a product or system parameter meet requirements.	✓				
C. Compatibility					
1. **Co-existence -** Degree to which a product can perform its required functions efficiently while sharing a common environment and resources with other products, without detrimental impact on any other product.	✓				
2. **Interoperability -** Degree to which two or more systems, products or components can exchange information and use the information that has been exchanged.		✓			
D. Reliability					
1. **Maturity -** Degree to which a system, product or component meets needs for reliability under normal operation.		✓			
2. **Availability -** Degree to which a system, product or component is operational and accessible when	✓				

required for use.					
3. **Fault tolerance -** Degree to which a system, product or component operates as intended despite the presence of hardware or software faults.	✓				
4. **Recoverability -** Degree to which, in the event of an interruption or a failure, a product or system can recover the data directly affected and re-establish the desired state of the system.	✓				
E. Security					
1. **Confidentiality -** Degree to which a product or system ensures that data are accessible only to those authorized to have access.	✓				
2. **Integrity -** Degree to which a system, product or component prevents unauthorized access to, or modification of, computer programs or data.		✓			
3. **Non-repudiation -** Degree to which actions or events can be proven to have taken place so that the events or actions cannot be repudiated later	✓				
4. **Accountability -** Degree to which the actions of an entity can be traced uniquely to the entity.		✓			
5. **Authenticity -** Degree to which the identity of a subject or resource can be proved to be the one claimed.	✓				
F. Maintainability					
1. **Reusability -** Degree to which an asset can be used in more than one system, or in building other assets.	✓				
2. **Analysability -** Degree of effectiveness and efficiency with which it is possible to assess the impact on a product or system of an intended		✓			

change to one or more of its parts, or to diagnose a product for deficiencies or causes of failures, or to identify parts to be modified.					
3. **Modifiability -** Degree to which a product or system can be effectively and efficiently modified without introducing defects or degrading existing product quality.	✓				
4. **Modularity -** Degree to which a system or computer program is composed of discrete components such that a change to one component has minimal impact on other components.		✓			
5. **Testability -** Degree of effectiveness and efficiency with which test criteria can be established for a system, product or component and tests can be performed to determine whether those criteria have been met.	✓				
G. Portability					
1. **Adaptability -** Degree to which a product or system can effectively and efficiently be adapted for different or evolving hardware, software or other operational or usage environments.	✓				
2. **Installability -** Degree of effectiveness and efficiency with which a product or system can be successfully installed and/or uninstalled in a specified environment.		✓			
3. **Replaceability -** Degree to which a product can replace another specified software product for the same purpose in the same environment.	✓				

Comments and Suggestions:

The Voice-controlled Wheelchair is commendable for its features. Instead of making a remote controlled wheel chair the group challenged themselves to make it more easy to use by making the wheelchair voice-controlled for easier use for the user. The wheelchair can move in all directions. The function to turn right, left, forward and backward can be completely done by the wheelchair even while carrying a heavy load such as the person with disability or sickness. The wheelchair is easy to operate because of its voice-controlled feature. Also, the wheelchair is integrated with the feature to locate when the user says kitchen, bedroom and other areas in the home which is impressive. Thus, its indoor auto-navigation system functioned completely. Despite carrying a heavy load the wheelchair moves high speed thus making the transportation of the person fast and accurate. The wheelchair can carry heavy person because of its high motor horsepower. The team choose the right DC motor which is 12 volts to install for each wheel of the voice-controlled wheel chair. The wheel chair navigated with ease and made sure that it moves within the space at the house. The system for the voice recognition and the rotating wheels exchanged information with correctness. The system work reliably operated for the use of transporting the person to areas within the home. The parts of the ChairLiDAR can easily be replaced by available parts in the market. The installation of the components were intact. The modification to be done was for the motor to possibly reduce the noise produced while running. Suggestion for this is to increase the attached insulation that will damp the noise produced by the motor. Since, the environment requires minimal noise. The ChairLiDAR is portable and can easily be transported from one place to another. The components were easyily installed in the residential environment.

Evaluated by:

Engr. Hanna Kathrine R. Ardan, RMEE

Signature over printed name

Technological University of the Philippines
Ayala Blvd., Ermita, Manila
College of Engineering
Electronics Engineering Department

Expert Evaluation Form (Based on ISO/IEC 25010)

Project Title: **ChairLiDAR: LiDAR-Based Voice-Controlled Wheelchair with Indoor Auto-Navigation System Using SLAM Algorithm for Quadriplegic Patients**

Name: Andrew Stephen Nacion
Age: 25
Sex: Male
Date Administered: 13/06/23
Time:
Administered by:
Name of the Company: Dyson
Address: Alabang, Muntinlupa
Designation: Software Engineer
Department: RDD - Embedded Software

Direction:
Please indicate a check mark (✓) under the column that best describes your responses for each item about the ChairLiDAR: LiDAR-Based Voice-Controlled Wheelchair with Indoor Auto-Navigation System Using SLAM Algorithm for Quadriplegic Patients. The rating scale is given below:

Numerical Rating	Equivalent
5	Excellent
4	Very Good
3	Good
2	Fair
1	Poor

INDICATORS	5	4	3	2	1
A. **Functional Suitability**					
1. **Functional completeness -** Degree to which the set of functions covers all the specified tasks and user objectives.			/		

2. **Functional correctness -** Degree to which a product or system provides the correct results with the needed degree of precision.			/		
3. **Operability -** Degree to which a product or system has attributes that make it easy to operate and control.jectives.		/			
B. Performance Efficiency					
1. **Time behavior -** Degree to which the response and processing times and throughput rates of a product or system, when performing its functions, meet requirements.		/			
2. **Resource utilization -** Degree to which the amounts and types of resources used by a product or system, when performing its functions, meet requirements.			/		
3. **Capacity -** Degree to which the maximum limits of a product or system parameter meet requirements.		/			
C. Compatibility					
1. **Co-existence -** Degree to which a product can perform its required functions efficiently while sharing a common environment and resources with other products, without detrimental impact on any other product.		/			
2. **Interoperability -** Degree to which two or more systems, products or components can exchange information and use the information that has been exchanged.	/				
D. Reliability					
1. **Maturity -** Degree to which a system, product or component meets needs for reliability under normal operation.		/			

2. **Availability -** Degree to which a system, product or component is operational and accessible when required for use.	/				
3. **Fault tolerance -** Degree to which a system, product or component operates as intended despite the presence of hardware or software faults.				/	
4. **Recoverability -** Degree to which, in the event of an interruption or a failure, a product or system can recover the data directly affected and re-establish the desired state of the system.				/	
E. Security					
1. **Confidentiality -** Degree to which a product or system ensures that data are accessible only to those authorized to have access.	/				
2. **Integrity -** Degree to which a system, product or component prevents unauthorized access to, or modification of, computer programs or data.	/				
3. **Non-repudiation -** Degree to which actions or events can be proven to have taken place so that the events or actions cannot be repudiated later		/			
4. **Accountability -** Degree to which the actions of an entity can be traced uniquely to the entity.			/		
5. **Authenticity -** Degree to which the identity of a subject or resource can be proved to be the one claimed.			/		
F. Maintainability					
1. **Reusability -** Degree to which an asset can be used in more than one system, or in building other assets.		/			
2. **Analysability -** Degree of effectiveness and efficiency with which it is possible to assess the					

impact on a product or system of an intended change to one or more of its parts, or to diagnose a product for deficiencies or causes of failures, or to identify parts to be modified.		/			
3. **Modifiability -** Degree to which a product or system can be effectively and efficiently modified without introducing defects or degrading existing product quality.			/		
4. **Modularity -** Degree to which a system or computer program is composed of discrete components such that a change to one component has minimal impact on other components.	/				
5. **Testability -** Degree of effectiveness and efficiency with which test criteria can be established for a system, product or component and tests can be performed to determine whether those criteria have been met.		/			
G. Portability					
1. **Adaptability -** Degree to which a product or system can effectively and efficiently be adapted for different or evolving hardware, software or other operational or usage environments.		/			
2. **Installability -** Degree of effectiveness and efficiency with which a product or system can be successfully installed and/or uninstalled in a specified environment.		/			
3. **Replaceability -** Degree to which a product can replace another specified software product for the same purpose in the same environment.			/		

Comments and Suggestions:

Suggestion:
- Add sensors or closed-loop system in Arduino Side for each value of angular and linear received
- Add Error Handling (Sensor status check, motor speed monitoring, MCU hanging or add watchdog)

Comment:
The researchers have demonstrated their ingenuity and dedication by developing a fully functional prototype of a LiDAR-Based Voice-Controlled Wheelchair. Although there is room for improvement in the autonomous navigation of the system, their achievement is commendable. Their innovative approach showcases their commitment to enhancing accessibility and mobility for individuals in need. With their expertise and determination, we can expect even greater advancements in the field of assistive technologies.

Evaluated By:

ANDREW STEPHEN NACION

Signature over printed name

Technological University of the Philippines
Ayala Blvd., Ermita, Manila
College of Engineering
Electronics Engineering Department

Expert Evaluation Form (Based on ISO/IEC 25010)

Project Title: **ChairLiDAR: LiDAR-Based Voice-Controlled Wheelchair with Indoor Auto-Navigation System Using SLAM Algorithm for Quadriplegic Patients**

Name: Jerick victorio
Age: 30
Sex:
Date Administered: June 12, 2023
Time:
Administered by:
Name of the Company:
Address:
Designation:
Department:

Direction:
Please indicate a check mark (✓) under the column that best describes your responses for each item about the ChairLiDAR: LiDAR-Based Voice-Controlled Wheelchair with Indoor Auto-Navigation System Using SLAM Algorithm for Quadriplegic Patients. The rating scale is given below:

Numerical Rating	Equivalent
5	Excellent
4	Very Good
3	Good
2	Fair
1	Poor

INDICATORS	5	4	3	2	1
A. Functional Suitability					
1. **Functional completeness -** Degree to which the set of functions covers all the specified tasks and user objectives.	✔				

2. **Functional correctness -** Degree to which a product or system provides the correct results with the needed degree of precision.	✔				
3. **Operability -** Degree to which a product or system has attributes that make it easy to operate and control.jectives.		✔			
B. Performance Efficiency					
1. **Time behavior -** Degree to which the response and processing times and throughput rates of a product or system, when performing its functions, meet requirements.		✔			
2. **Resource utilization -** Degree to which the amounts and types of resources used by a product or system, when performing its functions, meet requirements.	✔				
3. **Capacity -** Degree to which the maximum limits of a product or system parameter meet requirements.		✔			
C. Compatibility					
1. **Co-existence -** Degree to which a product can perform its required functions efficiently while sharing a common environment and resources with other products, without detrimental impact on any other product.		✔			
2. **Interoperability -** Degree to which two or more systems, products or components can exchange information and use the information that has been exchanged.		✔			
D. Reliability					
1. **Maturity -** Degree to which a system, product or component meets needs for reliability under normal operation.	✔				

2. **Availability -** Degree to which a system, product or component is operational and accessible when required for use.	✔				
3. **Fault tolerance -** Degree to which a system, product or component operates as intended despite the presence of hardware or software faults.			✔		
4. **Recoverability -** Degree to which, in the event of an interruption or a failure, a product or system can recover the data directly affected and re-establish the desired state of the system.		✔			
E. Security					
1. **Confidentiality -** Degree to which a product or system ensures that data are accessible only to those authorized to have access.		✔			
2. **Integrity -** Degree to which a system, product or component prevents unauthorized access to, or modification of, computer programs or data.		✔			
3. **Non-repudiation -** Degree to which actions or events can be proven to have taken place so that the events or actions cannot be repudiated later		✔			
4. **Accountability -** Degree to which the actions of an entity can be traced uniquely to the entity.		✔			
5. **Authenticity -** Degree to which the identity of a subject or resource can be proved to be the one claimed.	✔				
F. Maintainability					
1. **Reusability -** Degree to which an asset can be used in more than one system, or in building other assets.		✔			
2. **Analysability -** Degree of effectiveness and efficiency with which it is possible to assess the		✔			

impact on a product or system of an intended change to one or more of its parts, or to diagnose a product for deficiencies or causes of failures, or to identify parts to be modified.					
3. **Modifiability -** Degree to which a product or system can be effectively and efficiently modified without introducing defects or degrading existing product quality.		✔			
4. **Modularity -** Degree to which a system or computer program is composed of discrete components such that a change to one component has minimal impact on other components.		✔			
5. **Testability -** Degree of effectiveness and efficiency with which test criteria can be established for a system, product or component and tests can be performed to determine whether those criteria have been met.		✔			
G. Portability					
1. **Adaptability -** Degree to which a product or system can effectively and efficiently be adapted for different or evolving hardware, software or other operational or usage environments.		✔			
2. **Installability -** Degree of effectiveness and efficiency with which a product or system can be successfully installed and/or uninstalled in a specified environment.		✔			
3. **Replaceability -** Degree to which a product can replace another specified software product for the same purpose in the same environment.		✔			

Comments and Suggestions:

Great use of microcontroller with combination with lidar.

Evaluated By:

Jerick victorio

____

Signature over printed name

Technological University of the Philippines
Ayala Blvd., Ermita, Manila
College of Engineering
Electronics Engineering Department

Expert Evaluation Form (Based on ISO/IEC 25010)

Project Title: **ChairLiDAR: LiDAR-Based Voice-Controlled Wheelchair with Indoor Auto-Navigation System Using SLAM Algorithm for Quadriplegic Patients**

Name: BERUG, DONNIE
Date Administered: 6/14/2023
Name of the Company: TUP-M
Address: ERMITA, MANILA
Designation: INSTRUCTOR I

Age: 24
Time: 1:20 PM

Sex: M
Administered by:

Department: EE Dept.

Direction:
Please indicate a check mark (✓) under the column that best describes your responses for each item about the ChairLiDAR: LiDAR-Based Voice-Controlled Wheelchair with Indoor Auto-Navigation System Using SLAM Algorithm for Quadriplegic Patients. The rating scale is given below:

Numerical Rating	**Equivalent**
5	Excellent
4	Very Good
3	Good
2	Fair
1	Poor

INDICATORS	5	4	3	2	1
A. Functional Suitability					
1. **Functional completeness** - Degree to which the set of functions covers all the specified tasks and user objectives.			/		

2. **Functional correctness** - Degree to which a product or system provides the correct results with the needed degree of precision.			/		
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B. Performance Efficiency					
1. **Time behavior** - Degree to which the response and processing times and throughput rates of a product or system, when performing its functions, meet requirements.		/			
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3. **Fault tolerance** - Degree to which a system, product or component operates as intended despite the presence of hardware or software faults.				/	
4. **Recoverability** - Degree to which, in the event of an interruption or a failure, a product or system can recover the data directly affected and re-establish the desired state of the system.				/	
E. Security					
1. **Confidentiality** - Degree to which a product or system ensures that data are accessible only to those authorized to have access.			/		
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F. Maintainability					
1. **Reusability** - Degree to which an asset can be used in more than one system, or in building other assets.		/			
2. **Analysability** - Degree of effectiveness and efficiency with which it is possible to assess the		/			

impact on a product or system of an intended change to one or more of its parts, or to diagnose a product for deficiencies or causes of failures, or to identify parts to be modified.					
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1. **Adaptability** - Degree to which a product or system can effectively and efficiently be adapted for different or evolving hardware, software or other operational or usage environments.		/			
2. **Installability** - Degree of effectiveness and efficiency with which a product or system can be successfully installed and/or uninstalled in a specified environment.		/			
3. **Replaceability** - Degree to which a product can replace another specified software product for the same purpose in the same environment.		/			

Comments and Suggestions: things that could be added:

- Emergency breaks

- Bumpers

- Proper calibration of front wheels

Evaluated By:

ENGR. DONNIE BON L. BERUG

Signature over printed name

Technological University of the Philippines
Ayala Blvd., Ermita, Manila
College of Engineering
Electronics Engineering Department

Stakeholders Evaluation Form (Based on ISO/IEC 25010)

Project Title: **ChairLiDAR: LiDAR-Based Voice-Controlled Wheelchair with Indoor Auto-Navigation System Using SLAM Algorithm for Quadriplegic Patients**

Name: Gina B. Llano Age: 52 Sex: Female
Date Administered: 5/11/23 Time: Administered by:
Name of the Company: Tahanang Walang Hagdanan
Address: 175 aida st. Marick subd. cainta Rizal
Designation: Pettycash custodian Department: Treasury office

Direction:

Please indicate a check mark (✓) under the column that best describes your responses for each item about the ChairLiDAR: LiDAR-Based Voice-Controlled Wheelchair with Indoor Auto-Navigation System Using SLAM Algorithm for Quadriplegic Patients. The rating scale is given below:

Numerical Rating	Equivalent
5	Excellent
4	Very Good
3	Good
2	Fair
1	Poor

INDICATORS	5	4	3	2	1
A. Usability					
1. **Appropriateness recognizability -** Degree to which users can recognize whether a product or system is appropriate for their needs.		✓			

2. **Learnability** - Degree to which a product or system can be used by specified users to achieve specific goals of learning to use the product or system with effectiveness, efficiency, freedom from risk and satisfaction in a specified context of use, with the needed degree of precision.	✓				
3. **Operability** - Degree to which a product or system has attributes that make it easy to operate and control.		✓			
4. **User error protection** - Degree to which a system protects users against making errors.		✓			
5. **User interface aesthetics** - Degree to which a user interface enables pleasing and satisfying interaction for the user.	✓				
6. **Accessibility** - Degree to which a product or system can be used by people with the widest range of characteristics and capabilities to achieve a specified goal in a specified context of use.	✓				

Comments and Suggestions:

Evaluated By:

Gina B. Llano

Signature over printed name

Technological University of the Philippines
Ayala Blvd., Ermita, Manila
College of Engineering
Electronics Engineering Department

Stakeholders Evaluation Form (Based on ISO/IEC 25010)

Project Title: **ChairLiDAR: LiDAR-Based Voice-Controlled Wheelchair with Indoor Auto-Navigation System Using SLAM Algorithm for Quadriplegic Patients**

Name: DAVID VINCENT C. THBAWING Age: 53 Sex: Male
Date Administered: Time: Administered by:
Name of the Company:
Address: Novaliches, Q.C.
Designation: Communications Department:

Direction:
Please indicate a check mark (✓) under the column that best describes your responses for each item about the ChairLiDAR: LiDAR-Based Voice-Controlled Wheelchair with Indoor Auto-Navigation System Using SLAM Algorithm for Quadriplegic Patients. The rating scale is given below:

Numerical Rating	**Equivalent**
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INDICATORS	5	4	3	2	1
A. Usability					
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4. **User error protection** - Degree to which a system protects users against making errors.		✓			
5. **User interface aesthetics** - Degree to which a user interface enables pleasing and satisfying interaction for the user.		✓			
6. **Accessibility** - Degree to which a product or system can be used by people with the widest range of characteristics and capabilities to achieve a specified goal in a specified context of use.		✓			

Comments and Suggestions:

Very good.
Thanks for your empathy, which is a rare admirable trait. "Be proud of your kind ♡ not everybody has it."

Evaluated By: Dave Tabamag
DAVID VINCENT C. TABAMAG
Signature over printed name

Technological University of the Philippines
Ayala Blvd., Ermita, Manila
College of Engineering
Electronics Engineering Department

Stakeholders Evaluation Form (Based on ISO/IEC 25010)

Project Title: **ChairLiDAR: LiDAR-Based Voice-Controlled Wheelchair with Indoor Auto-Navigation System Using SLAM Algorithm for Quadriplegic Patients**

Name: Richard Arceno   Age: 54   Sex: Male
Date Administered: June 8, 2023   Time: 3pm   Administered by: Rhanzces Herrera
Name of the Company: Bigay Buhay Multipurpose Cooperative
Address: Block 7, Lot 26, Bach St., cor. Beethoven St. Phase 4, North Olympus, Barangay Kaligayahan, Quezon City
Designation: Chairman   Department: Office of the Chairman

Direction:
Please indicate a check mark (✓) under the column that best describes your responses for each item about the ChairLiDAR: LiDAR-Based Voice-Controlled Wheelchair with Indoor Auto-Navigation System Using SLAM Algorithm for Quadriplegic Patients. The rating scale is given below:

Numerical Rating	**Equivalent**
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INDICATORS	5	4	3	2	1
A. Usability					
1. **Appropriateness recognizability -** Degree to which users can recognize whether a product or		✓			

system is appropriate for their needs.					
2. **Learnability -** Degree to which a product or system can be used by specified users to achieve specific goals of learning to use the product or system with effectiveness, efficiency, freedom from risk and satisfaction in a specified context of use. with the needed degree of precision.		✓			
3. **Operability -** Degree to which a product or system has attributes that make it easy to operate and control.		✓			
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5. **User interface aesthetics -** Degree to which a user interface enables pleasing and satisfying interaction for the user.		✓			
6. **Accessibility -** Degree to which a product or system can be used by people with the widest range of characteristics and capabilities to achieve a specified goal in a specified context of use.		✓			

Comments and Suggestions:

The project is exciting to materialize. This will help the persons with extreme mobility challenges in particular the quadraplegic. We look forward to this technology being supported by the government and the interested donors for further research.

Evaluated By:

____
Signature over printed name

Annex VI

Project Documentation

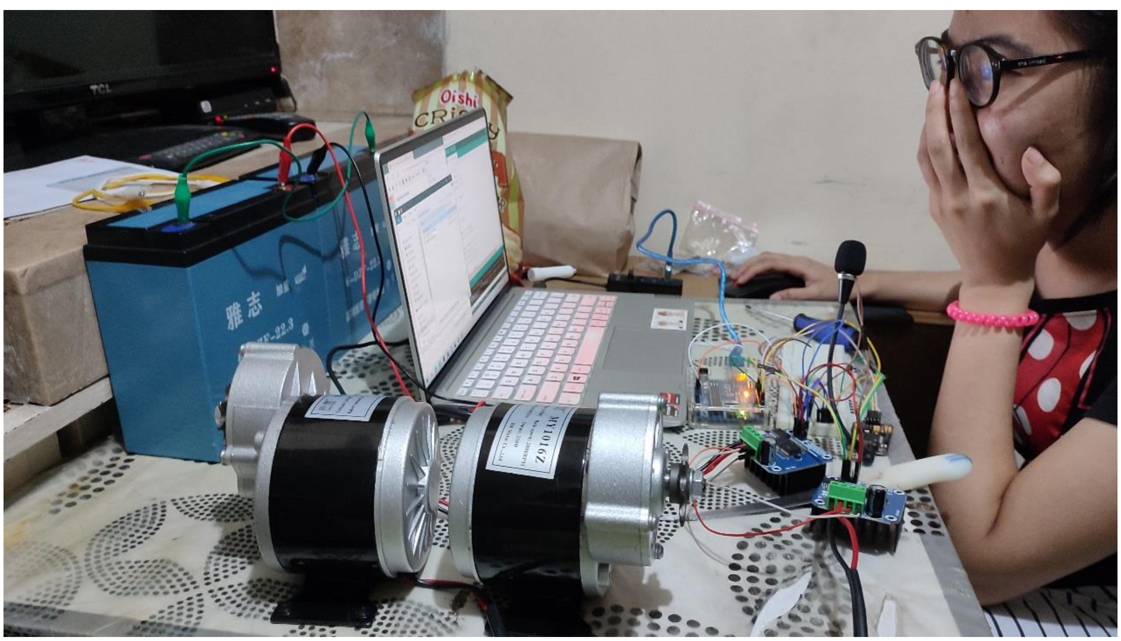
Installation of tubular metal for battery holder *(below the seat)* and circuitry platform *(at the back)*

Attachment of modified sprockets to the wheels

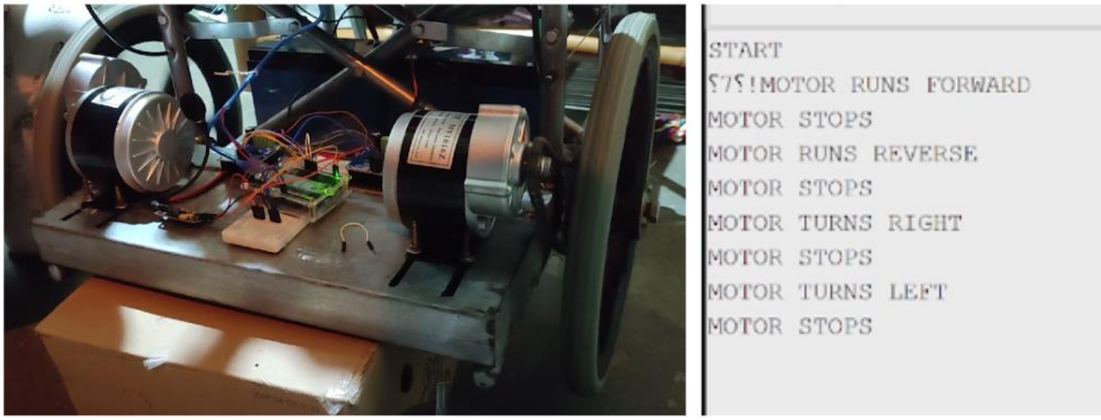
Installation of a DC motor on the circuitry platform at the back of the wheelchair

Installation of an extendable pole for the LiDAR sensor

Installation of an aluminum metal sheet for the battery enclosure

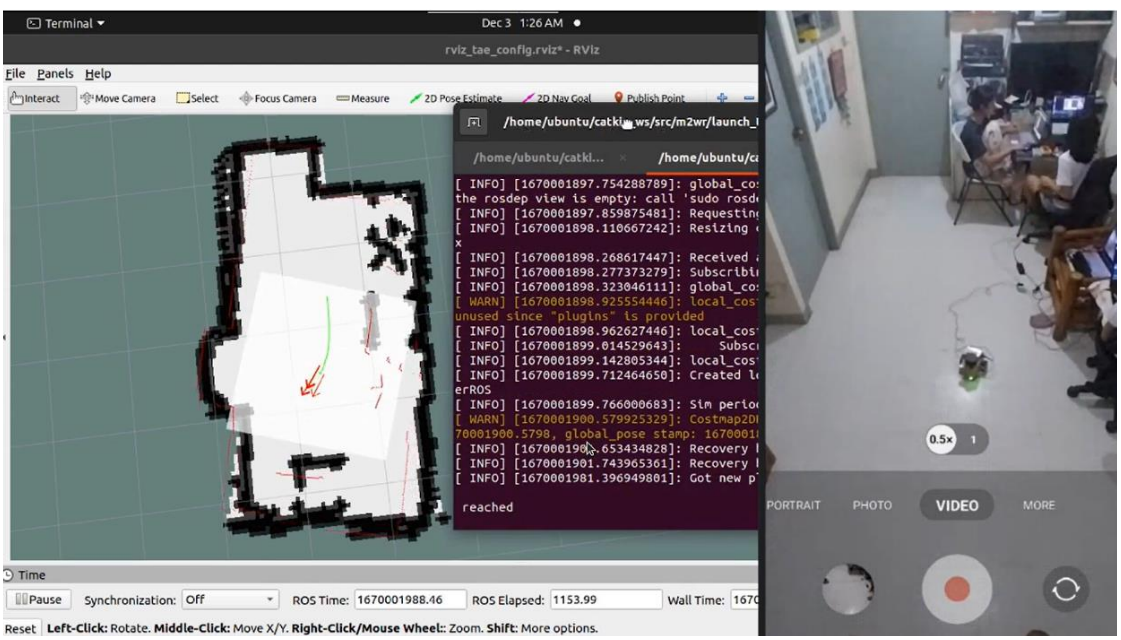


Testing the voice recognition system in relation to the movement of DC motors



Testing the voice recognition system by using basic commands in the wheelchair


Initial testing of obstacle avoidance using ultrasonic sensors in the robot car



Initial testing of the auto-navigation system in the robot car

Initial testing of the auto-navigation system with a user


Installation and connection of the components in their respective places

Installation of an enclosure for DC motors and a circuit box at the back of the wheelchair

ChairLiDAR deployed at Tahanang Walang Hagdanan, Inc. in Cainta, Rizal

Recording voice commands into the voice recognition module by User No. 1

Testing the voice recognition system with basic commands conducted by User No. 1

Testing the auto-navigation system performed by User No. 1

ChairLiDAR deployed at Bigay Buhay Multipurpose Cooperative in Quezon City

Mapping of a room in Bigay Buhay Multipurpose Cooperative via teleop control

Recording voice commands into the voice recognition module by User No. 2

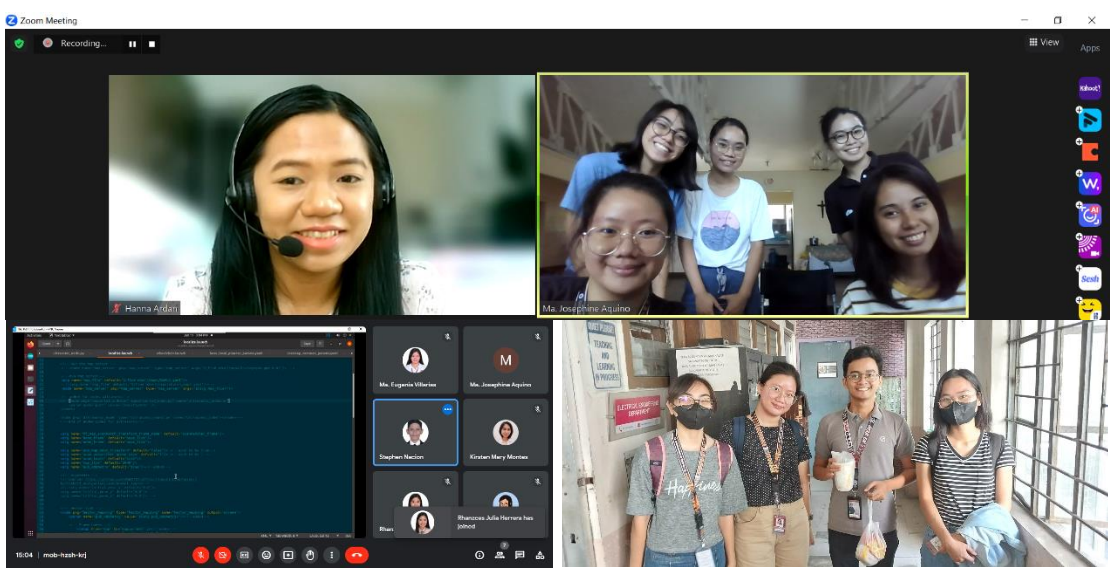
Testing the voice recognition system with basic commands conducted by User No. 2

Testing the auto-navigation system performed by User No. 2

Recording voice commands into the voice recognition module by User No. 3


Testing the voice recognition system with basic commands conducted by User No. 3

Testing the auto-navigation system performed by User No. 3



Consultation with experts including a Mechanical Engineer, Electronics Engineer, and Electrical Engineer

APPRECIATE 2023

Presentation of the prototype to the Department of Science and Technology (DOST)

Annex VII

ChairLiDAR User's Manual

ChairLiDAR:

LiDAR-Based Voice-Controlled Wheelchair with Indoor Auto-Navigation System Using SLAM Algorithm for Quadriplegic Patients

USER'S MANUAL

OVERVIEW

ChairLiDAR is an assistive device for individuals with limb impairments who cannot manually control wheelchairs. It uses a LiDAR sensor to create a 2D map of the surroundings and employs voice commands for navigation. The wheelchair avoids obstacles by utilizing the Simultaneous Localization and Mapping (SLAM) algorithm and 2 ultrasonic sensors in front and back of the wheelchair for additional safety measures for the user. ChairLiDAR enables basic voice and destination commands, automatically generating paths to desired locations within mapped indoor areas. Its goal is to enhance mobility and independence for users with limb impairments and the elderlies since their wrist are prone to become weak.

BEFORE STARTING

Important Note: The instructions provided below are specifically for authorized personnel responsible for setting up the system:

1. Ensure that the user already has trained and loaded commands into the voice recognition module.
2. Ensure that the voice_ultrasonic.ino is uploaded to the Arduino Mega and that the port is assigned to /dev/ttyACM1.
3. Ensure that the wheelchair.ino file is uploaded to the Arduino Uno with the port assigned to /dev/ttyACM0.
4. Ensure that the map loaded in Rviz is the map where the ChairLiDAR is deployed.

SETTING UP THE SYSTEM

Important Note: The instructions provided below are specifically for authorized personnel responsible for setting up the system:

1. Open the terminal and type "roslaunch ChairLiDAR wheelchair.launch".
2. Localize the ChairLiDAR properly in the map (arrows will be where the ChairLiDAR should be in the map, pointing towards the direction where it is facing). To localize ChairLiDAR, press the 2D Pose Estimate and click where the ChairLiDAR's position should be in the map. Note that the arrows will cluster and the lasers from the lidar will match with the map if the ChairLiDAR is already properly localized.
3. Speak basic voice commands or navigation commands to command ChairLiDAR to move after localization.

USING THE VOICE RECOGNITION MODULE

1. Clip the mic to the user’s shirt collar to ensure that the user’s voice would easily be picked up.
2. To navigate the wheelchair, simply use the basic commands such as “Forward”, “Backward”, “Left” and “Right”.
3. To navigate the wheelchair to specific locations of the indoor area, simply state the locations of where you want to go. Examples are “Bathroom”, “Kitchen”, “Bedroom”, etc. Make sure that this voice commands are already tested and recorded to the voice recognition module for these commands to work.
4. To stop the wheelchair from moving, a simple verbal command “Stop” can be used.

CHARGING OF BATTERIES

1. To charge the batteries, simply plug the provided charger into the port located at the bottom of the seat and wait for approximately 8-12 hours to fully charge.
2. A **RED** light on the charger indicates that the batteries are charging.
3. A **GREEN** light will appear when the ChairLiDAR is charged completely.

SAFETY PRECAUTIONS

It is of utmost importance to prioritize personal safety and prevent any potential harm by strictly following the instructions provided. **Make sure to have authorized personnel to check this for you as well.** Adhering to these guidelines plays a critical role in minimizing the risk of injuries or accidents and ensuring a safe environment.

1. Ventilation: To prevent heat build-up, monitor heat sinks from time to time to dissipate heat generated by the components. Open the back enclosure after every use to help maintain a suitable operating temperature and prevent the components from overheating.

2. Heat Insulation: To protect the ChairLiDAR and its components from potential damage caused by excessive heat, it is important to avoid prolonged exposure to direct sunlight or other high-temperature environments. Store the ChairLiDAR in shaded areas or indoors to minimize exposure to heat sources. Regularly inspect the wheelchair for any signs of heat-related damage and take appropriate action if detected.

3. Proper Wiring: Ensure that all electrical wiring within the circuit box is properly insulated and secured. Use wiring techniques that adhere to safety standards and regulations when fixing or troubleshooting problems encountered from the wires.

4. Regular Maintenance: Conduct periodic inspections and maintenance to ensure the integrity of the enclosure and its protective features. Check for any signs of damage, such as cracks, leaks, or compromised seals from batteries.

5. Water Avoidance: To prevent potential damage to the electrical circuitry and batteries, it is important to keep the ChairLiDAR always dry. Avoid exposing the wheelchair to water, including rain, puddles, and other sources of moisture. Water contact can result in malfunctions and pose safety risks.

6. Avoid Open Flames: Keep open flames, sparks, and smoking materials away from the batteries. Hydrogen gas released by the batteries is highly combustible, and any ignition source can lead to a fire or explosion.

7. Secure Handling: When moving or transporting the battery, ensure it is securely held and kept in an upright position. This helps to prevent damaging the wheelchair and minimizes the risk of short circuits.

8. Charging Safety: Avoid overcharging the battery, as it can lead to the release of harmful gases and can cause the battery to overheat or rupture.

9. Proper Connections: Ensure that the battery terminals are properly connected, and there are no loose or corroded connections. Loose connections can cause sparks and generate heat, which may lead to accidents or damage the battery.

10. Emergency Switch: Once the system malfunctions, **IMMEDIATELY** turn off the emergency switch located at the lower left side of the wheelchair. This will stop the whole system from operating.

TROUBLESHOOTING/ MAINTENANCE

Important Note: The following instructions are intended for authorized personnel with access to the system's component box. If you encounter any issues, please follow these steps to ensure the proper functioning of the system:

- If the ports for the Arduino Uno and Arduino Mega are not designated as /dev/ttyACM0 and /dev/ttyACM1 respectively, disconnect both Arduinos from the Raspberry Pi then connect the Arduino Uno first before reconnecting the Arduino Mega.
- If you notice a decrease with the wheelchair's speed, make sure to check your battery if it still has sufficient power to operate. Insufficient battery power greatly impacts the performance of the wheelchair.
- In case the voice recognition module is not working, check if the light is blinking when you speak. The blinking of the light indicates that the module is processing the voice input. If the light remains steady, ensure that the wires are connected properly or consult it with the authorized personnel to fix this issue.

Annex VIII

Manual for Duplicating the Prototype

MANUAL ON HOW TO DUPLICATE THE PROTOTYPE

INTRODUCTION

This manual provides comprehensive instructions on how to duplicate the prototype ChairLiDAR developed by the proponents of this study. An individual may be able to build a replica of this prototype by following the subsequent steps carefully and may ensure consistency and reliability in the manufacturing process.

SAFETY PRECAUTIONS

The following safety precautions must be followed before proceeding with the production process:

- Verify Equipment Compatibility: Before proceeding with the setup, confirm that all the equipment and devices are compatible with the system requirements. This includes checking compatibility with power sources, network connections, and any other necessary peripherals.
- Workspace Organization: Maintain a clean and well-organized workspace. Ensure that tools, equipment, and materials are properly stored and easily accessible. Minimize clutter and eliminate any potential tripping hazards.
- Electrical Safety: If the prototype involves electrical components or circuits, ensure that you have a clear understanding of electrical safety practices. Avoid working on live circuits whenever possible and use appropriate insulation and grounding techniques.

- Temperature Considerations: Lead-acid batteries can be sensitive to temperature extremes. Avoid exposing the battery to excessive heat or freezing conditions, as it can reduce its performance and lifespan.
- Power Isolation: Before making any modifications or repairs to the prototype, ensure that the power source is disconnected or switched off. This prevents accidental electric shocks or short circuits.
- Battery Handling: When moving or transporting the battery, ensure it is securely held and kept in an upright position. This helps to prevent acid spills and minimizes the risk of damage or short circuits. Avoid placing it directly on the ground to prevent moisture from seeping in. This might affect the performance and lifespan of the batteries.
- Emergency Preparedness: Be vigilant especially when working on circuit connections. In case of accidents or emergencies, know the appropriate procedures to follow and ensure access to necessary assistance.

MATERIALS AND EQUIPMENT

The following are the materials and equipment needed to recreate the prototype.

Materials:

See Annex IV for the complete list of materials.

Tools and Equipment:

For circuitry:

- Monitor, HDMI cable, HDMI to micro-HDMI connector, keyboard, and mouse – for setting-up the Raspberry Pi 4 B microprocessor.

- Multimeter
- Breadboard
- Wire Cutter
- Precision Tools
- Soldering Iron

For hardware part:

- Pliers
- Wrenches
- Hammer
- Screwdriver
- Drill

PROCEDURE

Preparation:

- Familiarize and analyze the original prototype, its features, and specifications.
- Gather all the necessary materials, tools, and equipment before starting the duplication process. Ensure that they are in good condition and properly calibrated.
- Make sure the area is clean, organized, and well-lit.

Step-by-step Procedure:

Software:

1. Set-up the Raspberry Pi 4 B and its micro-SD card by using monitor, HDMI cable, HDMI to micro-HDMI connector, keyboard, and mouse.
2. Install Ubuntu 20.04 OS on the Raspberry Pi 4 B.

3. Once Ubuntu setup is complete, install ROS Noetic into the system using the terminal.
4. Install Rviz in ROS Noetic using the terminal.
5. Create your catkin workspace.

Auto-Navigation System:

1. Gather all the necessary components for auto-navigation system such as Raspberry Pi, Arduino Mega 2560, Arduino Uno, RPLiDAR, wires and cables, and motor drivers.
2. Connect the motor drivers to the Arduino Uno using male-to-female jumper wires.
   - 2.1. Connect the VCC pins of the motor drivers to the VCC pin on Arduino Uno.
   - 2.2. Connect the GND pins of the motor drivers to the GND pin of Arduino Uno.
   - 2.3. For the left motor, connect the RPWM and LPWM to pins 7 and 6 of the Arduino Uno, respectively. Then connect its R-EN and L-EN to pin 3.
   - 2.4. For the right motor, connect the RPWM and LPWM to pins 2 and 9 of the Arduino Uno, respectively. Then connect its R-EN and L-EN to pin 10.
3. Connect the two motor drivers to the batteries.
   - 3.1. Connect the B+ of the two motor drivers to the positive terminal of the supply.

3.2. Connect the B- of the two motor drivers to the negative terminal of the supply.

4. Connect the motor drivers to their dedicated DC motors.

   4.1. Connect the positive and negative terminal of the left DC motor to the M+ and M- of the left motor driver.

   4.2. Connect the positive and negative terminal of the right DC motor to the M+ and M- of the right motor driver.

5. Enable communication between the Raspberry Pi and Arduino by installing Rosserial Arduino Library in the Arduino IDE.

6. Connect the RPLiDAR to the Raspberry Pi.

7. Test if the lidar is properly working.

   7.1. Open the terminal and go to the source directory of your catkin_ws.

   7.2. Clone the github repository https://github.com/robopeak/rplidar_ros.

   7.3. Change the mode of the port where the lidar is connected by entering: sudo chmod 666 /dev/ttyUSB0.

   7.4. Go back to your catkin workspace directory and source through the command: source devel/setup.bash.

   7.5. Run catkin_make.

   7.6. Enter in the terminal: roslaunch rplidar_ros view_rplidar.launch. This will prompt Rviz and show a generated 2D representation of the environment.

8. Install the necessary packages needed for localization and auto navigation such as the HectorSLAM, AMCL, and move base packages.
9. Connect the Arduino Uno to the Raspberry Pi and make sure that the port assigned to the Uno is /dev/ttyACM0.
10. Open the Arduino IDE and upload the codes to the Arduino Uno for motor control. *(Refer to Annex III)*
11. Map an indoor area where you want the ChairLiDAR to be deployed.
    - 11.1. Open a terminal and enter the command: roslaunch rplidar_ros rplidar.launch.
    - 11.2. Open another terminal and enter the command: roslaunch hector_slam_launch tutorial.launch. This will open a Rviz where you can see the map being generated. Note that obstacles from the lidar's point of view will also be detected so it is recommended to move obstacles away to generate a clearer map.
    - 11.3. Move the ChairLiDAR to map the area. You can either manually map the area by moving the ChairLiDAR or teleoperate it for a more convenient way of mapping.
    - 11.4. When the user is satisfied with the generated map, save the map by opening another terminal. Navigate to your desired directory then enter the command with the format: rosrun map_server map_saver -f [filename]. Example: rosrun map_server map_saver -f my_map
12. Load the generated or saved map into the system.

12.1. Navigate to the localize.launch file directory and open it. Note that the localize.launch file is located at Home/catkin_ws/src/chairlidar/launch/localize.launch.

12.2. Under the map_server node, change the args to the directory of your pre-saved map generated from mapping. Example: args="$(find m2wr)/maps/my_map 0.05"/>

13. Create a launch file for localization and place the necessary codes for the auto-navigation system. You may refer to Annex III of the manuscript.

Obstacle Detection and Avoidance System

1. Gather all the necessary components for the obstacle detection system such as Arduino Uno and Mega 2560, two ultrasonic sensors, breadboard, jumper wires, printed circuit board (PCB), and 22 AWG stranded wires.
2. Connect the ultrasonic sensors to the Arduino Mega 2560.

   2.1. Connect the VCC pin of the two ultrasonic sensors by pinning them on the holes of the same power bus.

   2.2. Use a male-to-male jumper wire with enough length to connect the 5V pin on the Arduino Mega 2560 to one of the holes of the same power bus where the two VCC pins of ultrasonic sensors are connected.

   2.3. Connect the GND pin of the two ultrasonic sensors by pinning them on the holes of the same ground bus.

2.4. Use a male-to-male jumper wire with enough length to connect the GND pin on the Arduino Mega 2560 to one of the holes of the same ground bus where the two GND pins of ultrasonic sensors are connected.

2.5. Connect the Trig and Echo pins of the two ultrasonic sensors to the analog pins on the Arduino. Place the ultrasonic sensors on the breadboard and use male-to-male jumper wires to connect them to the dedicated pins on the Arduino. In this study, the Trig and Echo pins of the first ultrasonic sensor placed at the armrest were connected to pins A2 and A3, respectively. Moreover, the Trig and Echo pins of the second ultrasonic sensor placed at the back of the wheelchair were connected to pins A6 and A7, respectively.

3. Open the Arduino IDE on your computer and create a new sketch for the codes.
4. Refer to Annex III for the codes of obstacle detection and avoidance system.
5. Connect the Arduino to your computer. Select “Arduino Mega 2560” as your board and make sure that you select the correct port in Arduino IDE.
6. Verify the codes first to see if there are any errors in the program. If there are any errors, check the code, connection, board, or port in Arduino IDE.

7. Upload the code for the obstacle detection and avoidance system to the Arduino Mega 2560.
8. Finalize the connection between the pins from ultrasonic sensors and Arduino Mega 2560 before using a PCB and stranded wires.

Voice Recognition System

1. Attach the lapel microphone to the microphone port of the voice recognition module.
2. Connect the Voice Recognition Module V3 to the Arduino Mega.
   - 2.1. Connect the VCC of the voice recognition module to the 5V of Arduino Mega.
   - 2.2. The TXD and RXD should be connected to pins 11 and 12 of the Arduino, respectively.
   - 2.3. Connect the GND pin of the voice recognition module by pinning them on the holes of the ground pin socket of the Arduino Mega.
3. Download the library for the Arduino voice recognition module V3.
4. Open the Arduino IDE and under Tools > Examples > VoiceRecognitionV3 click the “vr_sample_train” to train the module.
5. Change the baud rate to 57600, and the pins to the pins used in the Arduino Mega.
6. Save the Arduino as another file and upload it to the Arduino Mega. Note that the port of the Arduino Mega should be /dev/ttyACM1.
7. Train the voice recognition module V3.

7.1. Open the serial monitor and type in the training commands with the format: sigtrain (r) (sig). For example, “sigtrain 0 forward”. Note that the voice recognition module is only able to train 7 words.

7.2. Follow the instructions on the serial monitor. When it says, “speak now”, the user should dictate the desired command, and speak the command again when it shows “speak again.” The monitor will show “Trained” when the voice recognition module successfully recognizes the voice.

7.3. Load the recorded voice commands with the format: load (r0) (r1) …. For example, “load 0 1 2 3 4”. Try speaking the commands that have been recorded and see that the module recognizes your voice successfully.

Hardware:

Modify the wheelchair based on the figures shown in Annex I.

1. Modify the wheelchair by attaching first a 24T sprocket for each wheel.
2. Extend the back of the wheelchair by installing a flat metal or tubular metal where you will position the circuitry and DC motors.
3. Align the DC motor and the sprocket attached to the wheels on each side before adding the chains and finalizing the position of the wheels.
4. Create a case for the two 12-V lead acid batteries under the wheelchair.
5. Construct an enclosure for the circuitry and DC motors at the back of the wheelchair. Include a soundproof foam inside to lessen the acoustic noise produced by the DC motors.

6. Attach a pole where you will position the LiDAR sensor at the back of the wheelchair.
7. Install the ultrasonic sensors and voice recognition module with their cases at their respective placements.

TESTING

Once the prototype duplication process is done, test all the functionalities and performance of the duplicate prototype. Make any necessary adjustments or modifications to the prototype if needed.

Auto-Navigation System:

1. Run the launch file of the system in the terminal.
2. Once the RViz appears on the screen, check the localization of the wheelchair by observing the point clouds (red arrows) on the map if they point in the same position and direction of the wheelchair.
3. If the localization is inaccurate, click the 2D pose estimate tab (one with the green arrow icon) and point it to the real-time direction and position of the wheelchair to localize it on the map.
4. Click the 2D nav goal tab (pink arrow icon) then click on the map to where is the desired location.
5. Verify if the wheelchair followed the created path on the map and reached the goal.
6. If "goal reached" appeared on the terminal where the launch file was launched, then the auto-navigation feature is working properly.

Obstacle Detection and Avoidance System:

1. Test the system by uploading the code for ultrasonic sensors to the Arduino Mega 2560.
2. Open the terminal and type "rostopic echo /sonar_ranges_A" to verify the reading of ultrasonic sensor placed in front of the wheelchair, and "rostopic echo /sonar_ranges_B" for the ultrasonic sensor placed at the back of the wheelchair.
3. Run the main launch file of the system. Observe the dark blocks that appear around the LiDAR in RViz, which represent the detected obstacles near the wheelchair.
4. The testing of obstacle avoidance can be done by using the 2D nav goal function in RViz and placing obstacles along the pathway. Once the LiDAR and ultrasonic sensors detect the obstacle, observe whether the wheelchair will avoid the present obstacle.

Voice Recognition System:

1. Open the Arduino IDE and under Tools > Examples > VoiceRecognitionV3 click the "voice_sample_train" to train the module.
2. Load the recorded voice commands with the format: load (r0) (r1) …. For example, "load 0 1 2 3 4". Try speaking the commands that have been recorded and see that the module recognizes your voice successfully.
3. If every command appears on the screen, then the stored voice-commands after the training are recognized by the module.

TROUBLESHOOTING

- If the ports for the Arduino Uno and Arduino Mega are not designated as /dev/ttyACM0 and /dev/ttyACM1 respectively, disconnect both Arduinos from the

Raspberry Pi then connect the Arduino Uno first before reconnecting the Arduino Mega.

- In case that the serial monitor shows “No voice” in training the voice, the user should ensure that the microphone is properly connected to the voice recognition module.

MAINTENANCE

- Monitor the battery consumption from time to time for the wheelchair to operate properly.
- Make sure that the circuitry box receives proper ventilation to prevent the components from overheating.
- Avoid exposure to direct sunlight and any water sources to keep the prototype at its best condition. Moisture and excessive heat will cause the materials to reduce their functionality, performance and quality over time.
- To maximize the usage and durability of the voice recognition module's microphone, avoid putting undue stress on the wiring.

Annex IX

Proponents' Information

CRISNALYN B. AGUILAR

24 Kakawati., Western Bicutan, Taguig City

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Educational Background

Technological University of the Philippines – Manila — Expected Graduation: September 2023

Bachelor of Science in Electronics Engineering

Project Title: ChairLiDAR: LiDAR-Based Voice-Controlled Wheelchair with Indoor Auto-Navigation System Using SLAM Algorithm for Quadriplegic Patients

University of Makati — 2017 - 2019

Science, Technology, Engineering, and Mathematics (STEM)

Secondary Education — Senior High School

Fort Bonifacio High School — 2013 - 2017

Secondary Education — Junior High School

San Pedro Central Elementary School — 2007 - 2013

Primary Education

Experiences

Moderntech Computer System Inc. — August – October 2023

Worked as an intern with the role of IT Support Specialist. Tasks include assembling and configuring new PC units, and transferring files from the old units to new units through wired or wireless connections.

Technical Skills

- UI/UX Design (HTML & CSS)
- Basic Programming (Python, MATLAB, Arduino C++)
- Basic Networking Simulation (Cisco Packet Tracer, GNS3)
- Basic experience in simulation softwares (Simulink [MatLab], GNU Octave, Proteus, NI Multisim, MPLAB, DesignSpark)
- Microsoft Office (Word, Excel, PowerPoint, etc.)
- Basic Skills in Robot Operating System

MA. JOSEPHINE L. AQUINO

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Educational Background

Technological University of the Philippines – Manila Expected Graduation: September 2023
Bachelor of Science in Electronics Engineering
Project Title: ChairLiDAR: LiDAR-Based Voice Controlled Wheelchair with Indoor Auto Navigation System Using SLAM Algorithm for Quadriplegic Patients

Malayan Colleges Laguna 2017-2019
Science, Technology, Engineering, and Mathematics (STEM) Track
Secondary Education

United International Private School 2013-2017
Secondary Education

United International Private School 2007-2013
Primary Education

Experiences

Moderntech Computer System Inc. (MCSI) August 2022-October 2022
Student Intern (Customer Service, Encoder, and Data Management)

Technical Skills

- Basic Programming (Python, HTML, MATLAB, C++, R, CSS)
- Basic Networking Simulation (Cisco Packet Tracer, GNS3)
- Basic experience in Simulation Software (Simulink [MATLAB], GNU Octave, Proteus, NI Multisim, MPLAB, Design Spark)
- Basic Microsoft Office (Word, Excel, PowerPoint, etc.)
- Basic Video Editing Skills (Wondershare Filmora)
- Basic Skills in Robot Operating System (ROS)

RHOEVICK G. DE GUZMAN

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Educational Background

Technological University of the Philippines – Manila — Expected Graduation: August 2023
Bachelor of Science in Electronics Engineering
Project Title: ChairLiDAR: LiDAR-Based Voice Controlled Wheelchair with Indoor Auto-Navigation System Using SLAM Algorithm for Quadriplegic Patients

San Jose Academy — 2017-2019
Science, Technology, Engineering, and Mathematics (STEM) Strand
Secondary Education

Governor Andres Pascual College — 2013-2017
Secondary Education

Navotas Adventist Elementary School Inc. — 2006-2013
Primary Education

Experiences

Teleperformance — December 2022 - present
Customer Service Representative & Technical Support

Commsec Inc. — August 2022 - September 2022
Student Intern

Eton Global Institute Center for Culinary & Hospitality Management – Manila — February 2019
Work Immersion Student Intern

Technical Skills

- Basic Programming (Python, HTML, MATLAB, C++)
- Basic Networking Simulation (Cisco Packet Tracer, GNS3)
- Basic Skills in Simulation Software (Simulink [MATLAB], GNU Octave, Proteus, NI Multisim, MPLAB, Design Spark)
- Basic Microsoft Office (Word, Excel, PowerPoint, etc.)

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Educational Background

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Project Title: ChairLiDAR: LiDAR-Based Voice-Controlled Wheelchair with Indoor Auto-Navigation System Using SLAM Algorithm for Quadriplegic Patients

Village Montessori School 2013 - 2019
Secondary Education

Village Montessori School 2009 - 2013
Primary Education

Berlyn Academy 2007 - 2009
Primary Education

Experiences

On the Job Trainee August - September 2022
Commsec Inc.
Worked as one-month intern in the Operations Department of the Enterprise Project. Assisted in the installation of fiber equipment across the country, working with clients such as Converge and Huawei.

Technical Skills

- Proficient in Microsoft Office (Word, Excel, and PowerPoint)
- Basic Programming (Python, C++)
- Basic knowledge using Adobe Photoshop.

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Educational Background

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Project Title: ChairLiDAR: LiDAR-Based Voice-Controlled Wheelchair with Indoor Auto-Navigation System Using SLAM Algorithm for Quadriplegic Patients

Santa Rosa Science and Technology High School – Sta. Rosa City, Laguna — 2013 – 2019
Secondary Education

Chair of Saint Peter School – Balibago Complex, Sta. Rosa City, Laguna — 2007 – 2013
Primary Education

Experiences

MCSI (Moderntech Computer System Inc.) — August 2022 – October 2022
Student Intern (Data Management and Customer Service)

Technical Skills

- UX/UI Design
- Front-End Development (HTML & CSS, Macromedia Dreamweaver 8)
- Adobe CC Software (Photoshop, Illustrator, Premiere Pro, & After Effects)
- Proficient in Microsoft Office (Word, PowerPoint, Excel)
- Basic Programming (Python, MATLAB)
- Basic Network Simulation (Cisco, Packet Tracer, GNS3)
- Basic experience in simulation software (Simulink [MATLAB], DesignSpark, Proteus, GNU Octave, NI Multisim)

MA. EUGENIA Q. VILLARIAS

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Educational Background

Technological University of the Philippines – Manila — Expected Graduation: September 2023
Bachelor of Science in Electronics Engineering
Project Title: ChairLiDAR: LiDAR-Based Voice-Controlled Wheelchair with Indoor Auto-Navigation System Using SLAM Algorithm for Quadriplegic Patients

Filemon T. Lizan Senior High School — 2017-2019
Science, Technology, Engineering, and Mathematics (STEM) Track
Secondary Education

Navotas National Science High School — 2013-2017
Secondary Education

North Bay Boulevard Elementary School — 2007-2013
Primary Education

Experiences

Sysnet Integrators, Inc. — August 2022 – September 2022
Student Intern | Project Management and Engineering Department

Navotas City Hall — February 2019 – March 2019
Student Intern | City Engineering Office

Technical Skills

- Proficient in Microsoft Office
- Web Application Development (HTML, CSS, Macromedia Dreamweaver)
- Basic Programming (Python, C++, MATLAB, GNU Octave, R)
- Basic Knowledge in Simulation Software (NI Multisim, Proteus, Tinkercad, MATLAB Simulink)
- Basic Network Simulation (Cisco Packet Tracer, GNS3)
- Basic Photo and Video Editing Skills (Adobe Photoshop, Sony Vegas)
- Basic Skills in Robot Operating System (ROS)