HAPTIC-BASED PERSONALIZED SYSTEM INTERFACE USING HAND GESTURE SIGNAL FOR MOBILE ROBOT MOVEMENT

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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TAN CHEN LUNG

This report is submitted in partial fulfilment of the requirements for the degree of Bachelor of Electronic/Computer Engineering with Honours

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DEDICATION

I dedicate this research to my family, friends, and supervisor.

ABSTRACT

This project introduces a development in human-robot interaction through the creation of a haptic-based hand glove. The current lack of intuitive and natural interfaces for human-robot interaction, such as buttons or joysticks, is a significant challenge. The glove translates hand gesture signals into diverse mobile robot movement instructions, providing an intuitive and personalized control interface. The hand glove unit is constructed with flex sensors, transceiver, and vibration motor connected to Arduino Nano, while the mobile robot unit is constructed with transceiver, accelerometer, and L298N motor driver connected to Arduino UNO. Demonstrations across various environments validate the accuracy and versatility of the translated instructions. A haptic- based hand glove that can translate hand gesture signal into mobile robot movement is developed and the accuracy of the translated instruction is obtained by demonstrating mobile robot movement in different environments. The result of this project is obtained from the flex sensors of haptic-based hand glove and accelerometer reading from mobile robot unit. As part of future work, transitioning from half-duplex to full-duplex transceivers is suggested to enhance bidirectional communication, promising a more seamless and responsive interaction between users and mobile robots. This advancement marks a significant step towards a user-friendly and adaptable era in robotics.

ABSTRAK

Projek ini memperkenalkan pembangunan dalam interaksi manusia-robot melalui penciptaan sarung tangan berasaskan haptik. Kekurangan semasa antara muka intuitif dan semula jadi untuk interaksi manusia-robot, seperti butang atau kayu bedik, merupakan satu cabaran yang ketara. Sarung tangan menterjemah isyarat isyarat tangan ke dalam pelbagai arahan pergerakan robot mudah alih, menyediakan antara muka kawalan yang intuitif dan diperibadikan. Unit sarung tangan dibina dengan penderia flex, transceiver dan motor getaran yang disambungkan kepada Arduino Nano, manakala unit robot mudah alih dibina dengan transceiver, accelerometer dan pemandu motor L298N yang disambungkan kepada Arduino UNO. Demonstrasi merentas pelbagai persekitaran mengesahkan ketepatan dan kepelbagaian arahan yang diterjemahkan. Sarung tangan berasaskan haptik yang boleh menterjemah isyarat isyarat tangan ke dalam pergerakan robot mudah alih dibangunkan dan ketepatan arahan terjemahan diperoleh dengan menunjukkan pergerakan robot mudah alih dalam persekitaran yang berbeza. Hasil projek ini diperoleh daripada penderia lentur sarung tangan berasaskan haptik dan bacaan pecutan daripada unit robot mudah alih. Sebagai sebahagian daripada kerja masa hadapan, peralihan daripada transceiver half-duplex kepada full-duplex dicadangkan untuk *meningkatkan komunikasi dua hala, menjanjikan interaksi yang lebih lancar dan responsif antara pengguna dan robot mudah alih. Kemajuan ini menandakan satu langkah penting ke arah era robotik yang mesra pengguna dan boleh disesuaikan.*

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First and foremost, I express my sincere appreciation to my supervisor, TS. DR ZARINA BINTI MOHD NOH. Your mentorship, insightful guidance, and unwavering support have been instrumental throughout this research journey. Your commitment to excellence has shaped not only the content of this thesis but also my career.

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LIST OF SYMBOLS AND ABBREVIATIONS

AMR	:	Autonomous Mobile Robot
AGV	:	Automated Guided Vehicles
V-REP	:	Virtual Robot Experimentation Platform
AV	:	Augmented Virtuality
EMG	:	Electromyogram
VNC	:	Virtual Network Computing

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CHAPTER 1

INTRODUCTION

1.1 Project Background

The field of robotics has made significant progress in recent years, with robots being used in various applications, including manufacturing, healthcare, and exploration. However, one of the key challenges in robotics is designing robots that can interact with humans in a natural and intuitive way. Haptic feedback is a promising technology that can help to overcome this challenge by providing tactile sensations to the user during interaction with the robot [1].

The Haptic-based Personalized Monitoring System Interfacing Using Hand Gesture Signal for Mobile Robot Movement is a project that aims to develop a system that can enable users to control the movement of a mobile robot using hand gesture signals. The system uses haptic feedback to provide the user with tactile feedback during interaction with the robot. The project is motivated by the need for more intuitive and natural ways of interacting with robots, particularly in scenarios where traditional interfaces, such as buttons or joysticks, are impractical or cumbersome. The system has the potential to improve accessibility to technology for people with disabilities or impairments, by providing an alternative way of controlling the robot through hand gestures.

Overall, this addresses the need for more intuitive and natural ways of interacting with robots and has the potential to improve accessibility to technology and enable new applications in different fields such as health care, education, assistive technology, and more [2].

1.2 Problem Statement

There are situations where it is dangerous for humans to reach a place such as in a toxic environment or in a small and enclosed space [3]. Still, these dangerous places need to be reached for surveillance purposes or sometimes for early condition monitoring in 'search-and-rescue' tasks. Also, the interaction of humans with robots is lacking intuitive and natural ways. Traditional interfaces, such as buttons or joysticks, can be cumbersome and require specific training to use effectively. In addition, these interfaces can be difficult to use for people with disabilities or impairments.

With the advancement in robotic field, it is possible to have a remote-controlled robot that can reach these dangerous environments instead of human [4]. Hence, this project aims to demonstrate the movement of a mobile robot remotely by the control of a haptic-based personalized monitoring system using hand gestures signal interface. The application of haptic-based system and hand gesture signal as the robot controller can open wide possibilities for the system application such as a computer or a smartphone in virtual reality environment for immersive experience [5].

1.3 Objectives

The objectives of this project are to:

1. Develop a haptic-based hand glove that can translate hand gesture signal into several mobile robot movement instructions.

2. Obtain the accuracy of the translated instruction by demonstrating the mobile robot movement in different environments.

1.4 Scope of Work

The work of this project focuses on the development of the system prototype which consists of hardware components, such as sensors (flex sensors) and actuators (DC motor) that can detect the hand gesture signal for mobile robot movement. The block diagram of the overall system is as shown in Figure 1.1. In the haptic-based hand glove part, flex sensors serve as input devices interfacing with an Arduino Nano microcontroller. Simultaneously, the system incorporates an accelerometer for precise motion tracking, vibration motors for haptic feedback, and a transceiver for communication purposes, constituting the output elements of this subsystem. On the other hand, the mobile robot part integrates a transceiver as its input interface to communicate with an Arduino UNO microcontroller. This communication facilitates the reception of gesture-based commands. Subsequently, the mobile robot subsystem employs an accelerometer for orientation detection, a motor driver for controlling DC motors, and the DC motors themselves as output components. This cohesive integration of hardware elements forms a comprehensive framework for haptic gesture recognition and mobile robot movement. The demonstration of the mobile robot movement will be tested in three different environments that are ideal, on the lawn, and on the road.

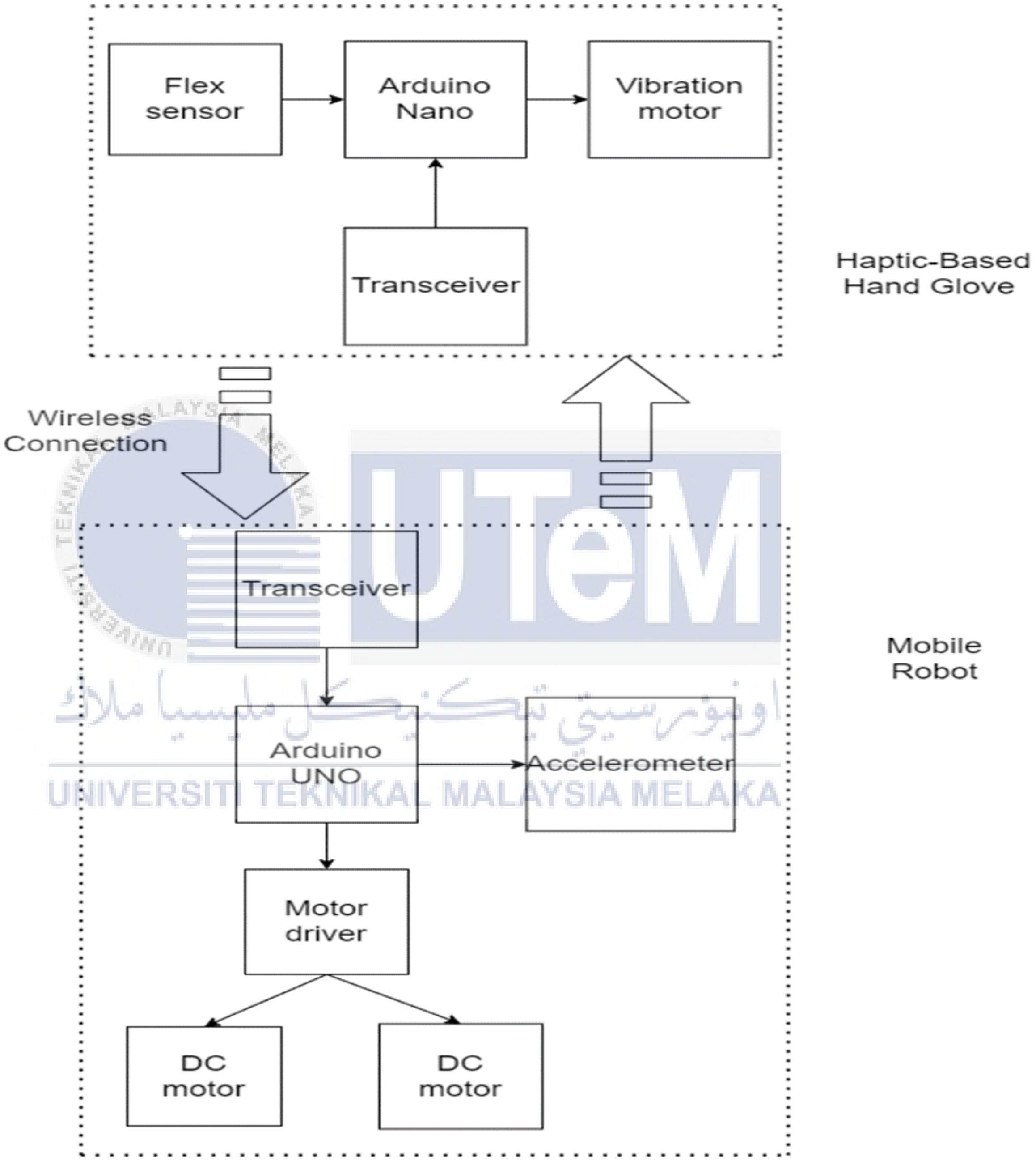


Figure 1.1: Project Block Diagram

1.5 Report Outline

There are five chapters in this report which consists of this chapter as the Introduction, Chapter 2 for the Literature Review, Chapter 3 for the Project Methodology, Chapter 4 for the Results and Analysis, and Chapter 5 for the Conclusion and Future Work.

Chapter 1 introduces the topic of the project and provides background information on why it is important. It also outlines the objectives of the project and explains the scope of work that will be used to achieve those objectives.

In Chapter 2, the existing literature related to the project topic has been reviewed and analyzed. The chapter concludes with a summary of the key findings from the literature review.

Chapter 3 describes the research methodology used in the project, including the project flowchart, development of a haptic-based hand glove and mobile robot prototype, and demonstration of the mobile robot movement in different environments.

Chapter 4 presents the findings from the data analysis, using tables, figures, and descriptive statistics to illustrate the results. The chapter also includes a discussion of the results.

Chapter 5 provides a summary of the project, including a restatement of the objectives and key findings. It also offers recommendations for future research. The chapter concludes with a reflection on the project's limitations and suggestions for improving future research on the topic.

CHAPTER 2

BACKGROUND STUDY

2.1 Mobile Robot Movement

Mobile robot systems have become more and more embedded in modern industrial production systems in recent years. When talking about mobile robots' different terms are used. The most common ones are autonomous mobile robots (AMRs) and automated guided vehicles (AGVs) and up to now, there is no absolutely clear distinction established [6]. Mobile robots can be used in various applications, such as manufacturing, logistics, agriculture, healthcare, and space exploration. For example, in manufacturing, mobile robots can transport materials and parts between different stations, assemble products, and perform quality control tasks. In logistics, mobile robots can be used for order picking, inventory management, and delivery. In agriculture, mobile robots can monitor crops, perform tasks such as spraying and harvesting, and reduce labor costs [7].

The ability of a mobile robot to move and navigate in a given environment is critical for its performance and effectiveness. The robot's movement capability depends on various factors, such as the type of locomotion, the sensors and actuators used for navigation, the control algorithms, and the environment's characteristics [8]. Autonomous robot navigation in unfamiliar environments presents formidable challenges. The robot must grapple with intricate issues such as accurately perceiving its surroundings, determining its precise location amidst uncertainties, and devising intricate path planning strategies to negotiate through the complex terrain. Moreover, the regulation of movements becomes a critical aspect, demanding real-time adjustments to avoid obstacles and respond to dynamic changes. These challenges underscore the need for advanced navigation controllers that blend reactive and deliberative approaches. The incorporation of a neuro-fuzzy system, coupling neural networks with a fuzzy logic controller, offers a promising avenue for addressing these hurdles. Experimental validation using an amigo Bot equipped with a Kinect sensor, in tandem with the Virtual Robot Experimentation Platform (V-REP) and ROS Groovy Galapagos, provides a testing ground to explore and refine corrective decisional commands, advancing the efficacy of autonomous navigation in unpredictable environments [9]. With that, an alternative for robot navigation is through human assistance by means of interfacing controller for human-computer interaction, which will be explored in the following section.

2.2 Human-Computer Interaction by Hand Gesture Signal

The main purpose of human–computer interaction is to allow users to freely control the device with some simple operations. Human–computer interaction techniques include face recognition, language recognition, text recognition, and so on. As one of the important and powerful interaction methods, dynamic hand gesture recognition has attracted wide attention and been used in various fields, such as the video game industry, food industry, and machinery industry [10]. The architecture of a hand gesture recognition system can be observed in Figure 2.1, where the hand gesture recognition system starts with hand gesture data collection. This is to collect more data on different hand gestures by the user so as to process the data collected which is the second process in Figure 2.1. Then, the data is then implanted into the system to do training and classification. After that, the recognition system is tested for output prediction.

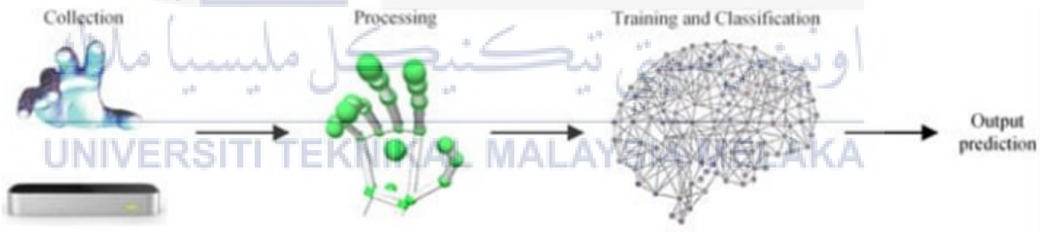


Figure 2.1: The architecture of the hand gesture recognition system [10].

A hand gesture signal for controller refers to the use of hand gestures as a means of controlling a device, such as a computer or a mobile phone. In this context, hand gestures are used to send commands to the device, such as scrolling, clicking, zooming, or rotating. Hand gesture recognition technology is used to identify and interpret the hand gestures made by the user and convert them into corresponding commands for the device. Hand gesture signal for controller is needed because it offers a more natural and intuitive way of interacting with devices, especially in situations where traditional input devices like a keyboard or mouse may not be practical or efficient. For instance, in gaming, hand gesture signal for controllers can provide a more immersive experience by allowing the player to physically interact with the game environment using hand gestures. Similarly, in virtual reality, hand gesture signal for controllers can provide a more immersive and realistic experience by allowing users to interact with the virtual world using natural hand movements [11]. Hand gesture signal for controllers can also improve accessibility to technology, especially for people with physical disabilities who may have difficulty using traditional input devices. For example, people with limited mobility or dexterity can use hand gesture signal for controller to interact with devices hands-free, making it easier and more convenient for them to perform tasks [12].

In terms of hand gesture signal as robot controller, the users need to know the exact movement or route taken by the robot for purposeful navigation. The movement or route taken can be given to the user either through a display system or other notifications. Still, if the environment is dark with low illumination, the user cannot grasp the surrounding environment navigated by the robot. In this kind of situation, intuitive feedback is useful as user’s assistance in navigating the challenging path, which can be obtained through haptic-based system. The following section will cover the details of haptic-based system and its application in robotics.

2.3 Haptic-Based System

Structurally, bodies of organisms can be described as tensegrity systems, fractally self-similar from whole-body to cellular levels. Sensory receptors embedded within such somatic tensegrity systems comprise haptic perceptual systems. Because the elements of the organismic tensegrity system are all interconnected, that system becomes the medium for haptic perception. Forces acting on any element of a somatic tensegrity system radiate throughout the entire system and thereby affect the entire haptic medium. All perception, from the ecological view, requires active sampling of stimulus arrays. Such active perception always involves overt body movements, orienting responses, and sensory organ adjustments (e.g., eye movements). All movements occasioned in active perception affect the organismic tensegrity system, and therefore the haptic medium that leads to the concept of haptic-based system [13].

A haptic-based system is a technology that provides users with tactile feedback, also known as haptic feedback, through the sense of touch. This technology is designed to simulate physical sensations and provide users with a more realistic and immersive experience when interacting with devices or virtual environments. Haptic-based systems have various applications, such as in gaming, virtual reality, and teleoperation. For instance, in gaming, haptic feedback can be used to enhance the player's experience by providing feedback on in-game events, such as weapon recoil, explosions, or collisions. In virtual reality, haptic feedback can be used to provide a more realistic and immersive experience by simulating physical sensations, such as the texture of an object or the sensation of movement.

Haptic-based systems are needed because they can enhance the user's experience and provide more intuitive and realistic interactions with devices and virtual environments [14]. An example of remote human-robot interaction system is as shown in Figure 2.2. The developed application comprises two interconnected workspaces: a local space, where users employ an AV headset to visualize a robotic system and its surroundings modeled in a virtual environment; and a remote workspace, where the robotic system operates. In the local space, virtual objects mirror their real-world counterparts through sensor measurements, integrating a vision system for precise object localization. Safety measures include a Kinect v2 depth sensor for non-modeled data, enabling users to verify virtual-physical alignment. An F/T sensor halts robotic motion in case of abnormal force/torque measurements, enhancing security. A haptic stylus facilitates teleoperation, providing force feedback for realistic control and tactile sensing of virtual objects. In remote space, the robot's high-level controller interprets haptic commands, adjusting the robot's position and orientation based on user inputs and vision system data, thereby ensuring effective and secure teleoperation for various applications.

By providing tactile feedback, haptic-based systems can simulate physical sensations, such as texture, temperature, or pressure, which can improve the user's sense of presence and immersion in a virtual environment. Moreover, haptic-based systems can improve accessibility to technology for people with visual or auditory impairments, by providing an alternative way of receiving information through the sense of touch.

In robotics area, the application of haptic-based system had made its way as robotic arm controller that can remotely collect samples in contaminated area [15]. This haptic robotic arm enables users to maneuver the robot and experience touch sensations akin to those of a human arm. The project aims to propose a haptic system implemented and tested using a cost-effective, off-the-shelf microcontroller. A basic two-servo-motors setup serves as a test platform to demonstrate the haptic feedback system. Results reveal that the proposed haptic system effectively responds to perturbations applied to the controlled servo motor, providing tactile feedback to corresponding 'human' servo motors. These findings underscore the feasibility of a low-cost haptic feedback system, laying the foundation for potential expansion into more intricate systems, such as simulating human fingers for delicately grasping objects. With that, a haptic-based system is a promising system that can be applied to robotics area where it can provide feedback to users intuitively through the sense of touch.

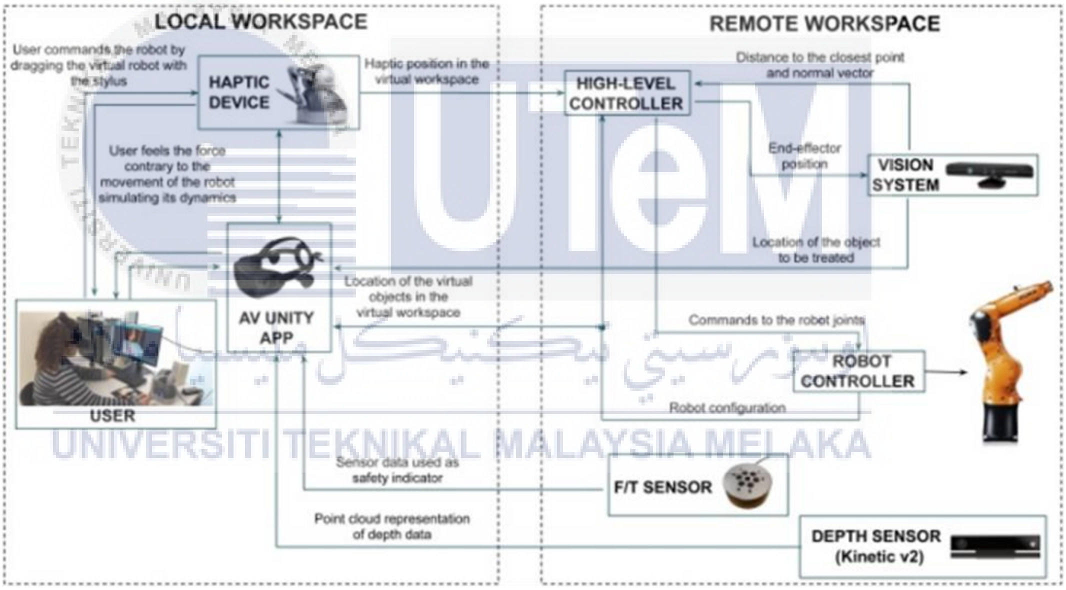


Figure 2.2: Remote human-robot interaction system using Augmented Virtuality with data from depth sensors and haptics to feel the robot movement [14].

2.4 Related Work on Mobile Robot Movement and Its Interaction with Hand Gesture Signals

There are several research have been found which are written by other researchers regarding mobile robot movement and hand gesture signals. One of the research projects is entitled Hand Gesture Based Mobile Robot Control Using PIC Microcontroller [16]. This system is designed to enable users to control the movement of a mobile robot using hand gestures. It is comprised of two main components, the gesture unit and the mobile robot unit as shown in Figure 2.3. In the gesture unit, a PIC microcontroller is employed to monitor finger movements and transmit corresponding control signals to the mobile robot unit. This unit is equipped with flex sensors and XBee-S1 modules to detect and interpret the gestures made by the user. The mobile robot unit also utilizes a PIC microcontroller to control the actual movement of the robot. The prototype of Hand Gesture Based Mobile Robot Control Using PIC Microcontroller is as given in Figure 2.6. It is equipped with peripherals such as XBee-S1 and L293DNE to facilitate wireless communication and motor control. Both units are powered by separate battery sources. This system is designed to be cost-effective and efficient, and it can be implemented in various applications, including assisting individuals with speech impairments by holding speakers and in the realm of toys [16].

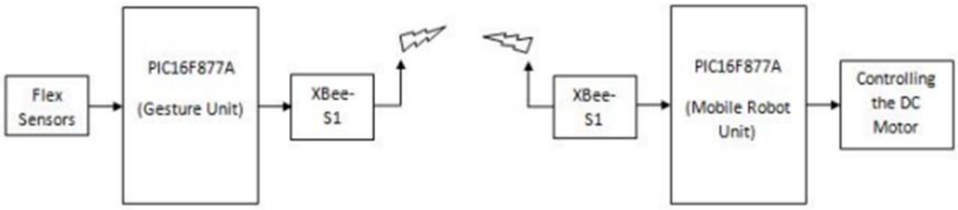


Figure 2.3: Block diagram for the proposed system [16].

Table 2.1: Code generation for the corresponding hand gestures [16].

Hand Gesture	**Generated Code at Gesture Unit**	**Actions of Mobile Robot Unit**	**Values Passed to PORTD**
	0	Stop	0X00
	1	Forward	0X03
	2	Reverse	0X0C
	3	Forward Right	0X02
	4	Forward Left	0X01
	5	Reverse Right	0X04
	6	Reverse Left	0X08

The types of hand gestures that have been used in controlling the mobile robot movement is as shown in Table 2.1 [16]. The glove used in the system contains five flex sensors that are connected to separate analog channels of the PIC microcontroller. Initially, when the flex sensors provide a zero output, the PIC microcontroller sends a code value of '0' to the mobile robot unit through the XBee-S1 module. The XBee-S1 module is connected to the USART channel of the PIC microcontroller to facilitate communication. When any of the flex sensors detect a change, the PIC microcontroller reads the corresponding gesture and generates the appropriate code. The different gestures, their corresponding code generation, and the actions performed by the mobile robot unit based on the received codes were also given in Table 2.1 [16].

The prototype of glove unit and mobile robot unit for the system is given in Figure 2.4.

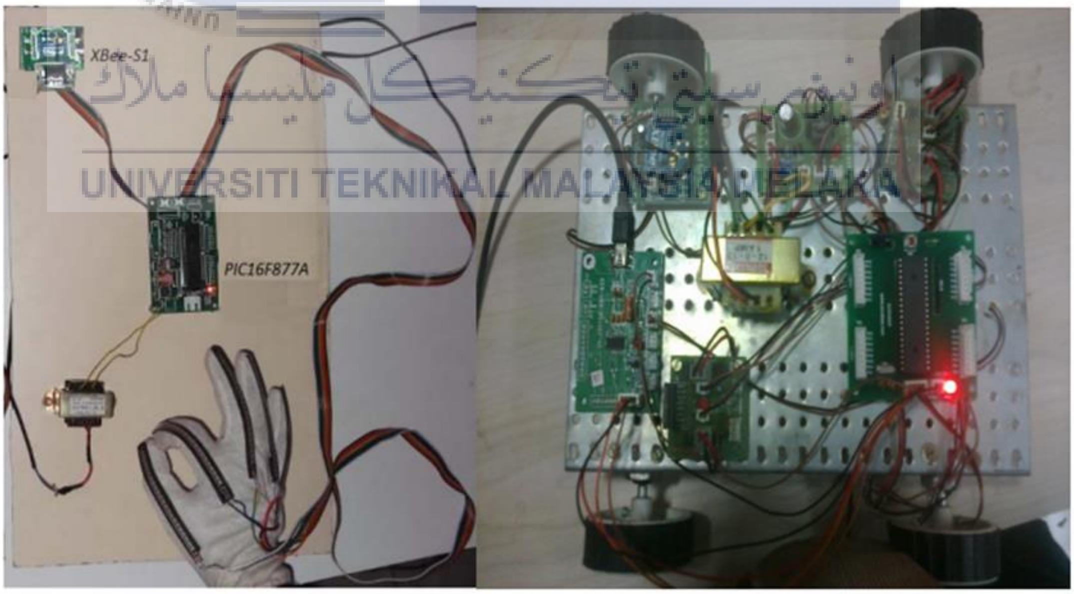


Figure 2.4: The glove unit and mobile robot unit [16].

In other research, a design of mobile robot navigation had been developed by using neuro-fuzzy logic system [9]. Robotics is an interdisciplinary field that combines electronics, mechanics, and information technology to develop robots, with a focus on creating autonomous robots that mimic human abilities. The integration of artificial intelligence (AI) technologies, such as fuzzy logic controllers (FLC) and neural networks (NN), plays a crucial role in mobile robot navigation. Navigational sensors, including cameras and distance sensors, enable robots to recognize and respond to their environment, with a particular emphasis on obstacle avoidance. Researchers have been actively working on evolving navigation systems for mobile robots, addressing challenges in dynamic environments. While reactive navigation is suitable for unknown settings, the proposed neuro-fuzzy system discussed in this paper efficiently combines high-level deliberate navigation planning and reactive low-level navigation control, offering a comprehensive solution for effective robotic navigation in diverse scenarios.

Figure 2.5 discusses two primary approaches to robotic navigation, namely the deliberative and reactive [9]. In the deliberative approach, a sampling-based algorithmic method is employed to design a course based on a discrete map of the environment, including unknown or probabilistic occupancy values. In contrast, the reactive approach involves generating potential fields considering the robot's location, objective, and known/unknown obstacles, which are then translated into reference velocities for the robot. The study integrates findings from both approaches to assess safety factors, such as the feasibility of intended paths and proximity to obstacles. The proposed approach consists of five components, emphasizing the use of sensors and actuators for environmental traversal and map reconstruction. The simulation involves a 2D plane with varying obstacle scenarios and considers the uncertainty of starting to pose information on the map.

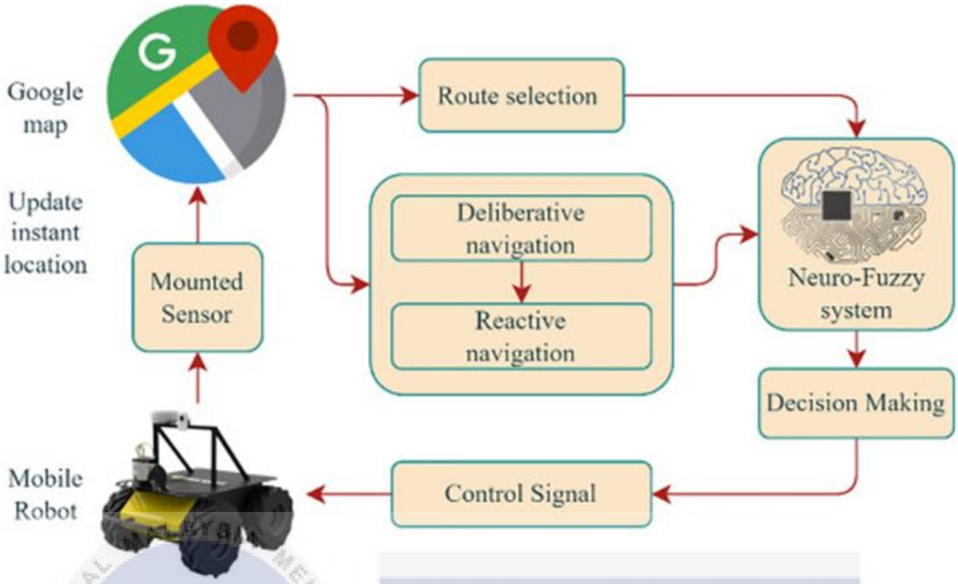


Figure 2.5: Framework of the Mobile Robot Navigation [9].

In another system, the researcher had developed on electromyogram-based hand gesture control system [17].

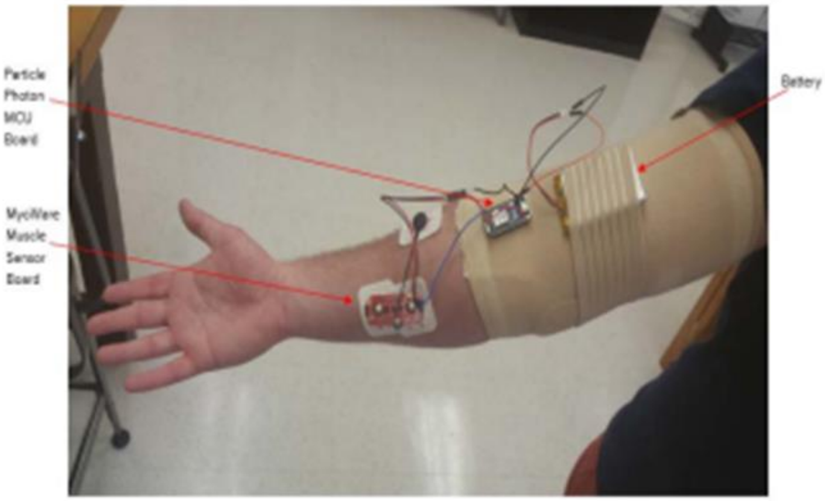


Figure 2.6: EMG control subsystem[17].

The EMG control subsystem makes use of a MyoWare muscle sensor board and a Particle Photon microcontroller board for analyzing, categorizing, and transmitting signals. The MyoWare muscle sensor board, depicted in Figure 2.6, employs electrodes positioned on the forearm muscle to detect the electrical potential generated by muscle contractions. The muscle sensor board enhances, rectifies, and integrates the EMG signal. Subsequently, the STM32F205 ARM Cortex M3 microcontroller on the Particle Photon board converts the signal into a digital format using a 12-bit analog-to-digital converter (A/D) [17].

The overall block diagram of the EMG-based hand gesture control system is as shown in Figure 2.7.

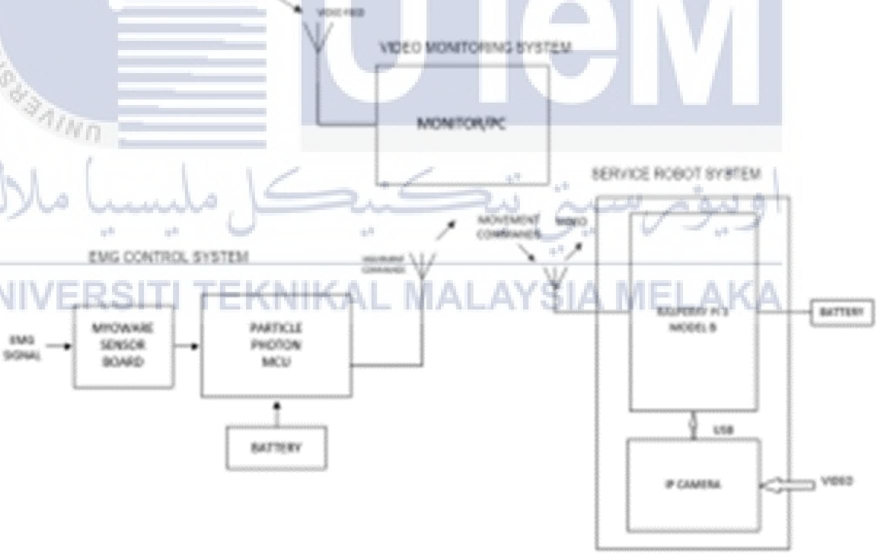


Figure 2.7: System block diagram [17].

The system consists of three main subsystems, namely the EMG control, wheeled service robot, and monitor. To read EMG signals from the user, a MyoWare muscle sensor board is employed, which transmits the signals to the analog-to-digital converter of the Particle Photon for advanced signal processing. The Photon then performs system calibration for the user, utilizing an artificial neural network (ANN) to classify four different commands. Once the signals are classified and calibrated, the user can send one of four commands to control the robot via WiFi. These commands include forward, stop, left, and right motor control commands, which the user needs to calibrate using hand and finger movements. The wheeled service robot receives the command through a TCP/IP protocol established by the Particle Photon board. The Raspberry Pi reads the command and generates specific pulse width modulation (PWM) signals to control the robot's movement. Additionally, the Raspberry Pi sets up a web server that displays the user's four commands and provides live video feedback of the robot's path on a computer monitor [17].

Another interesting system that implements the hand movements to control a robotic vehicle is as shown in Figure 2.8 [18]. This robotic vehicle can be controlled in all directions using hand movements, along with a wireless camera mounted on top of the vehicle for live streaming to the user. This system eliminates the need for gesture recognition, image processing techniques, switches, or joysticks typically used for robot control. Additionally, it provides wireless surveillance capabilities to the user.

The system consists of three main components, namely the transmitter, the receiver, and the live streaming section. The transmitter section detects hand movements in the x and y axes using an accelerometer sensor, which is processed by an Arduino Uno. The signals are then transmitted to the receiver section via an RF module. The transmitter part is designed to be worn on the user's hand for controlling the movement of the robotic vehicle in various directions. It consists of an accelerometer connected to an Arduino Uno microcontroller. The accelerometer senses the position of the hand in the x and y axes and converts these movements into analog signals. These signals are then transmitted to the Arduino Uno. The Arduino Uno processes the analog signals using built-in functions such as Pitch and Roll to compare the hand movements in the x and y axes. Based on this comparison, the Arduino Uno generates the necessary commands to move the robotic vehicle in different directions [18]. In the receiver section, the signals are received by another Arduino Uno, decoded, and sent to the motor driver, which is connected to the Arduino Uno as shown in Figure 2.8. The motor driver controls the movement of the robotic vehicle in various directions based on the decoded signals. To enable live streaming, a laptop, Raspberry Pi, and two software tools, Virtual Network Computing (VNC) and Foundation Internet Nouvelle Generation (FING), are used in conjunction with a common Wi-Fi network. The setup ensures that the user can access the live surveillance feature as shown in Figure 2.12. The control commands transmitted by the RF transmitter are received by the RF receiver and forwarded to the Arduino Uno. The Arduino Uno decodes these commands by comparing them with its programmed values, creating digital signals. These digital signals are then sent to the motor driver, which interprets them as input commands. Consequently, the motor driver operates the motors in various directions, such as left, right, forward, and backward, based on the output commands from the Arduino Uno as shown in Figure 2.11. This allows the robotic vehicle to move accordingly [18].

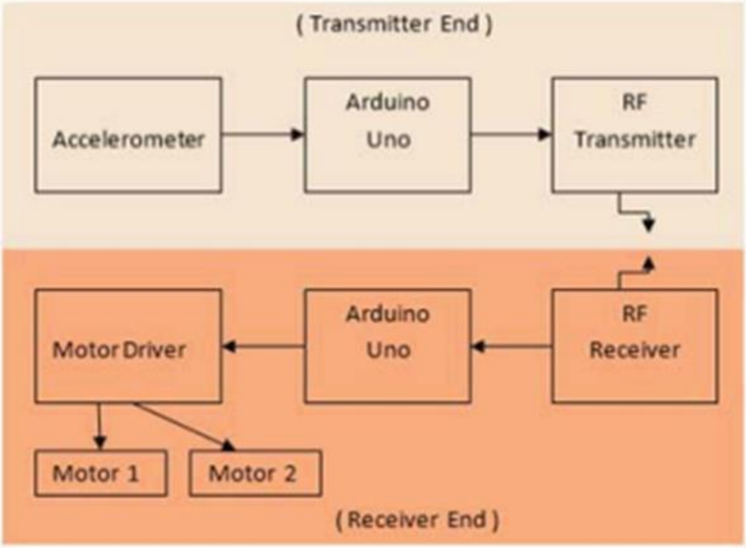


Figure 2.8: Block diagram of the working principle of the robotic vehicle [18].

Figure 2.9 illustrates the connection between the motor driver, Arduino Uno, and motors. The motor driver receives commands from the Arduino Uno and controls the rotation of the motors accordingly.

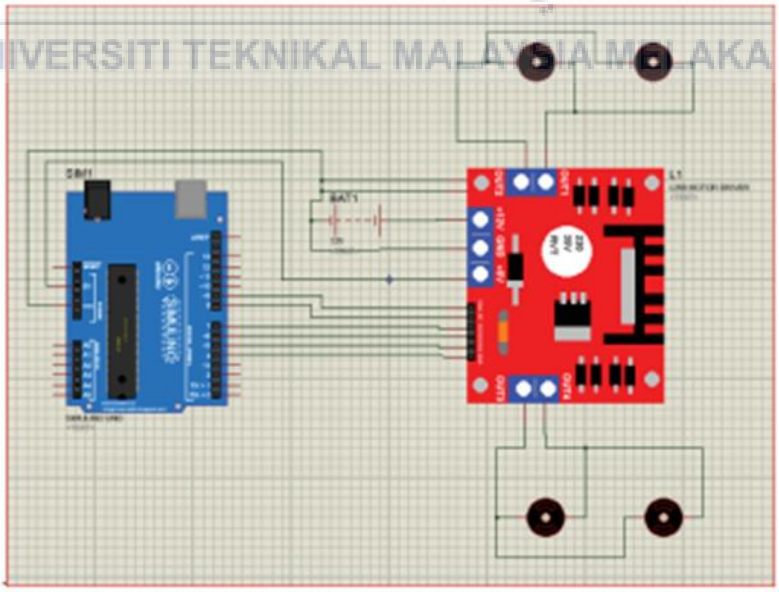
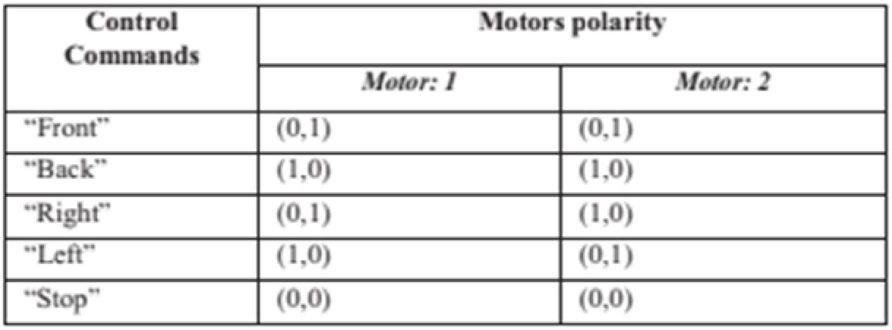


Figure 2.9: Circuit diagram of motor driver (L298) connected with Arduino Uno and motors [18].

Figure 2.10 provides information about the different polarities of the motors, indicating the specific directions in which they will move [18].



Control Commands	Motors polarity	
	Motor: 1	*Motor: 2*
"Front"	(0,1)	(0,1)
"Back"	(1,0)	(1,0)
"Right"	(0,1)	(1,0)
"Left"	(1,0)	(0,1)
"Stop"	(0,0)	(0,0)

Figure 2.10: Polarity of the motors according to the control commands [18].

Figure 2.11: Position of the hand along with the transmitter part to move the robotic vehicle in different directions [18].

*Figure 2.12: An 8 mega pixel webcam connected with the raspberry pi [18]***.**

The control commands generated by the hand movements at the transmitter end to maneuver the robotic vehicle in different directions are detected by an accelerometer sensor and processed by an Arduino Uno. At the receiver end, these commands are decoded and sent to the motor driver, which serves as the final input for controlling the movements of the robotic vehicle. Another Arduino Uno is responsible for decoding and delivering these commands to the motor driver [18].

The last literature review discusses the conceptual design of a haptic feedback controller for a robotic arm intended for remote sample collection in contamination areas, particularly when dealing with delicate samples [15]. The haptic robotic arm allows users to control movement and experience touch sensations similar to a human arm. The project aims to propose a low-cost haptic system implemented and tested using off-the-shelf microcontrollers. A simple two-servo-motors test setup demonstrates the feedback of the proposed haptic configuration. The results indicate that the system effectively responds to perturbations on the controlled servo motor, providing a sense of touch back to corresponding 'human' servo motors. This low-cost approach shows promise for expanding the haptic feedback system to more complex applications, such as mimicking human fingers for handling delicate objects.

Figure 2.13 shows the block diagram for simple haptic feedback system, the haptic will be transmitted between Servo 2 and Servo 0 by a feedback proportional controller with gain k. The value for gain k can be adjusted for the amount of feeling to be felt by user at Servo 0. Figure 2.14 shows the block diagram in Figure 2.13 that is connected physically as a test setup.

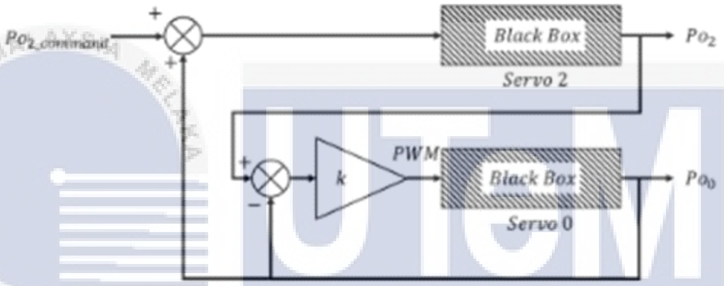


Figure 2.13: Block Diagram for Simple Haptic Feedback System [15].

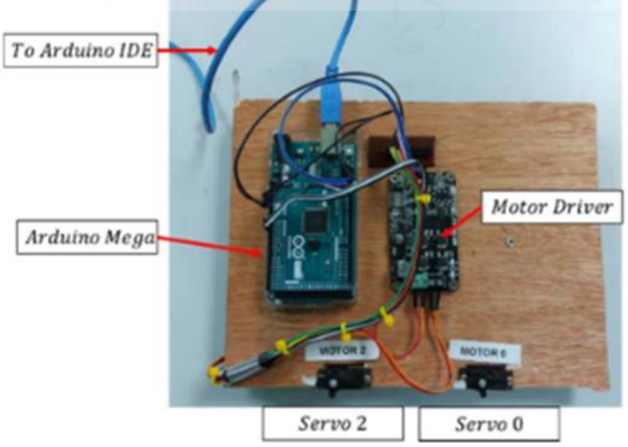


Figure 2.14: Haptic Feedback Test Setup [15].

Although the current implementation successfully incorporates haptic feedback, the presented results do not provide a comprehensive evaluation of the feedback system's efficacy. To address this limitation, a more thorough assessment is recommended by integrating the haptic feedback controller into a complete robotic arm. This holistic testing approach would allow for a more nuanced understanding of the system's capabilities in conveying tactile sensations, including nuanced touch and weight perception. Notably, the utilization of a feedback gain set at 10 reveals a persistent steady-state error between input and output movements, indicating a potential area for improvement. In response to this, transitioning from an open-loop to a closed-loop system is proposed, with the addition of an integrator to regulate Servo 2 and effectively eliminate the observed steady-state error. Such refinements would likely enhance the overall performance and responsiveness of the haptic feedback system, contributing to its feasibility in practical applications [15].

2.5 Summary of Literature Review

Table 2.2 shows the summary of literature review which there are 5 literature reviews that have been done. The selection of these five literatures is likely driven by their alignment with the key aspects of the project, including hand gesture control, haptic feedback, wireless features, and advanced control systems. Reviewing these works can offer a comprehensive understanding of existing methodologies, technologies, and challenges in the respective areas, aiding in the project's development and innovation.

Table 2.2: Summary of Literature Review.

System	Title	Input Components	Output Components	Wireless Communication	Advantage/Limitation
Hand gesture based system [16]	Hand Gesture based Mobile Robot Control Using PIC Microcontroller	Flex sensors	DC motor	XBee-S1	In this proposed work, gesture based mobile robot control is successfully developed and implemented in real time environment. This system is developed at low cost, low power and time. The system provides better performance in the experimental setup. As of now the range of communication between the mobile robot and the user is 10m.
EMG-based hand gesture control system [17]	EMG-based hand gesture control system for robotics	MyoWare muscle sensor,	DC motor, monitor subsystems	TCP/IP 802.11 protocol	The system can calibrate and classify EMG signals from different movements performed by the system users. The communication system was successful in transmitting commands from EMG control subsystem to be received accurately by the service robot system. A web server was implemented to

System	Title	Input Components	Output Components	Wireless Communication	Advantage/Limitation
					provide live video feedback and instructions to the user.
Security Surveillance System [18]	Design and Implementation of a Hand Movement Controlled Robotic Vehicle with Wireless Live Streaming Feature	Accelerometer	DC motor	RF transmitter and receiver	The robotic vehicle is designed to move any direction by using just the hand movement of the user. Moreover, there are some precarious places or situations, where it is shaky to send a human to observe those places; but this designed robotic vehicle can be sent over there to observe the real scenario of those places.
Haptic feedback system [15]	Conceptual Design and Implementation of a Low-Cost Haptic Feedback Controller	Potentiometer	Servo motors	-	To enhance implementation accuracy, certain refinements can be applied. Through careful analysis, an optimal value for the proportional controller gain is identified at approximately 10. This choice facilitates commendable transient performance, as evidenced by the achievement of the desired output from Po 2 within a rapid 1-second rise time. This simple yet effective concept and implementation pave the way for the expansion of a cost-effective haptic system, enabling the replication of functional human operations, such as the intricate movements of fingers for grasping and the strength of an arm for lifting.

System	**Title**	**Input Components**	**Output Components**	**Wireless Communication**	**Advantage/Limitation**
Neuro-fuzzy logic system [9]	Design of mobile robot navigation controller using neuro-fuzzy logic system	Mounted sensor	Mobile robot	Deliberative navigation and Reactive navigation	The suggested navigation framework aims to capitalize on the advantages of both reactive and deliberative navigation while mitigating their individual drawbacks, such as local optima and planning time. A method leveraging the neuro-fuzzy system is devised to integrate commands derived from each approach, establishing priorities in case of conflicts. The reactive layer employs mapping data and the immediate surroundings of the mobile robot asynchronously. On the other hand, deliberative navigation utilizes a sampling algorithm with the concept of probabilistic completeness in varied environments, thereby reducing planning time.

CHAPTER 3

METHODOLOGY

3.1 Project Flowchart

For Objective 1, the flowchart starts by doing research on literature review. After that, the design of the circuit and hardware will be constructed so as to have a draft of the project. After designing the circuit and hardware, each component that is needed will be collected as listed out. There are two circuits that needed to be constructed which are the PCB of transmitter part placed on top of the glove. The other one is the PCB of receiver part which will be placed on top of the mobile robot. The program development for the two microcontrollers of the transmitter and receiver part will be done so as the glove and mobile robot will function. After the circuits have been done, the integration part of the circuit and program will be done. Then, the prototype will be tested out whether it is working as expected or not. If the prototype is not working as expected, the problems will be determined and troubleshooted. If the prototype is working, it will proceed to the next process which is Objective 2, the prototype will be demonstrated on three different environments which are ideal, on the lawn, and on the road to test its capabilities. Analysis on the prototype accuracy will also be done by collecting the reading of the x,y,z from the accelerometer. In the end, the improvement of the prototype will be done.

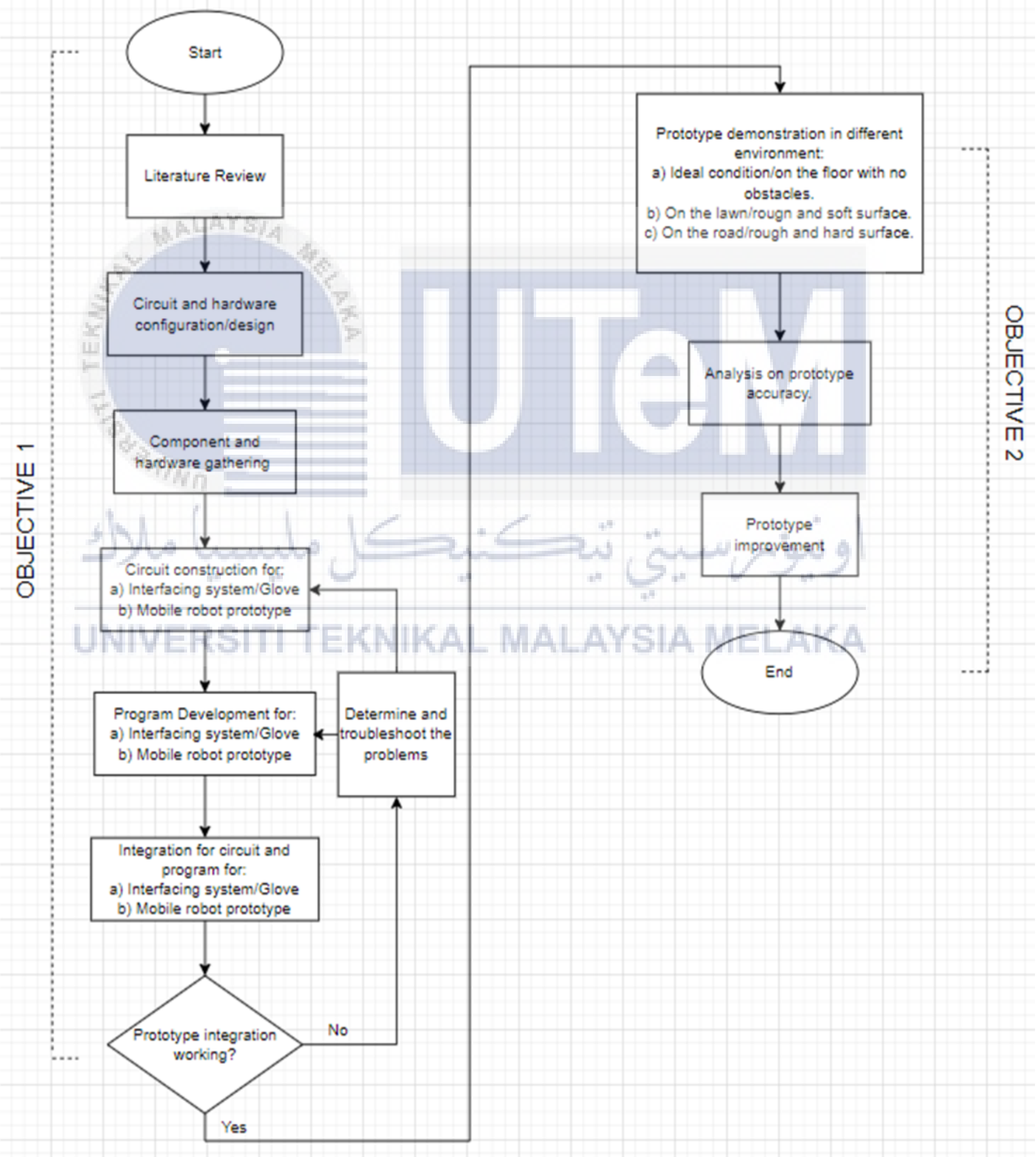


Figure 3.1: Project Flowchart.

3.2 Development of a Haptic-Based Hand Glove and Mobile Robot Prototype

Figure 3.2 shows the block diagram of the prototype which has the haptic-based hand glove and mobile robot part. For the haptic-based hand glove part, flex sensors act as the input to the Arduino Nano, while accelerometer, vibration motor, and transceiver act as the output. For the mobile robot part, transceiver acts as the input of Arduino UNO, while accelerometer, motor driver, and DC motors act as the output.

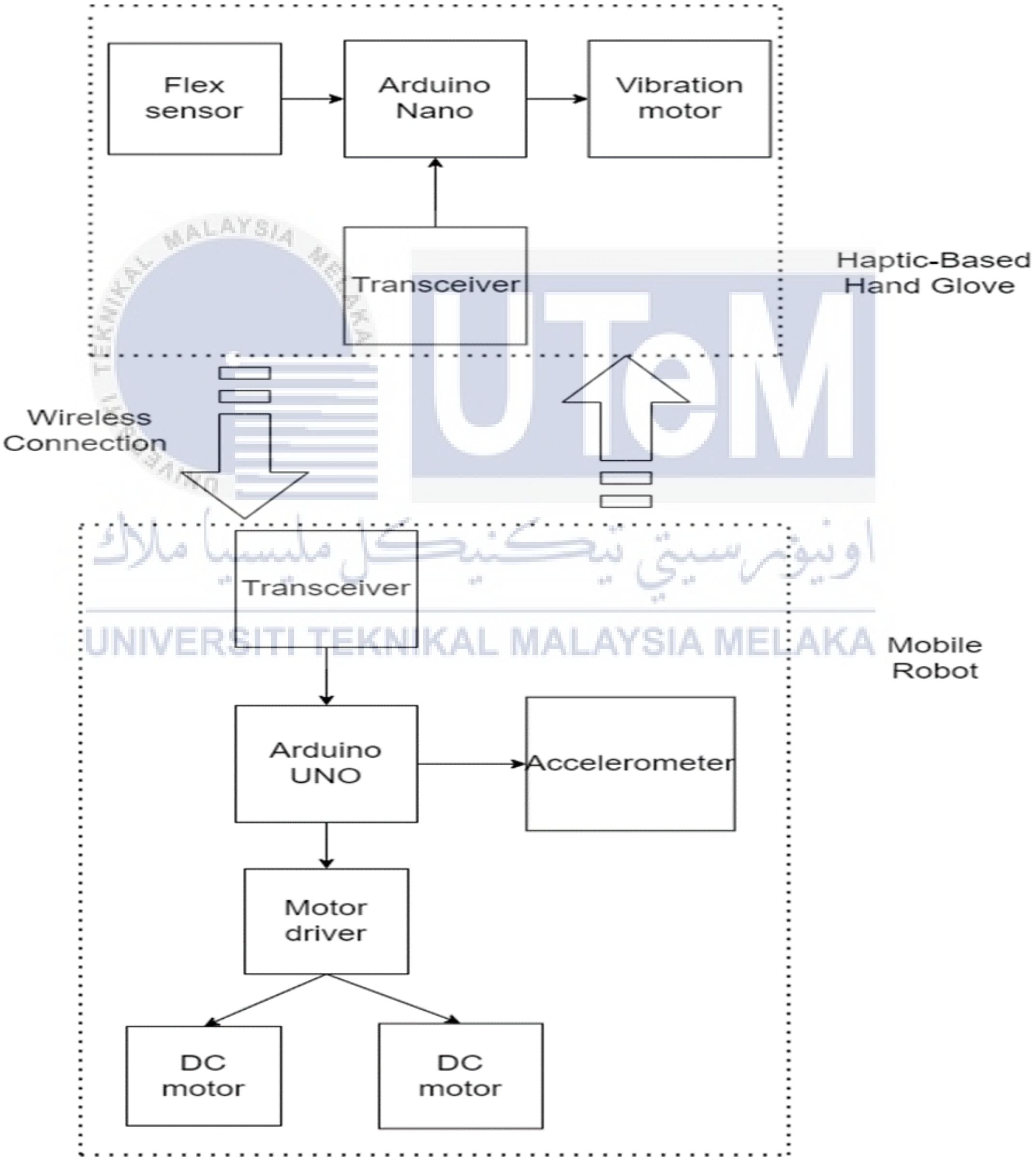


Figure 3.2: Project block diagram.

3.2.1 Hardware Development

In haptic-based hand glove unit, flex sensors are used to identify the hand gestures of the user. As the sensors fall under the category of resistive type of sensor, so whenever the sensor is bent, the resistance value will increase. The resistance value will be sent to the Arduino Nano to convert it as a command and then transmit the signal to Arduino Uno on the mobile robot unit through transceivers. As a haptic-based hand glove, the vibration motor on the hand glove will act as haptic feedback to the user. Whenever the mobile robot is moving according to the hand gestures of the user, the vibration motor will vibrate once to let the user realize that the mobile robot is moving.

Figure 3.3 shows the connection of all components for hand glove unit part. Five flex sensors are connected to Arduino Nano so that the reading of the flex sensors bending can be read. Transceiver is also connected to Arduino Nano so that the signals from mobile robot unit can be received. The vibration motor is connected so that it will provide haptic feedback whenever the mobile robot is moving.

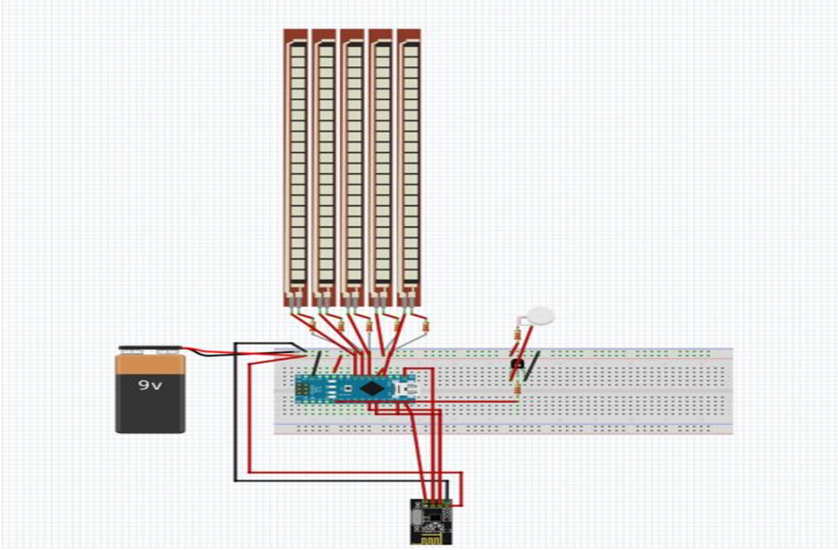


Figure 3.3: Schematic circuit of the hand glove unit.

Table 3.1: Summary of the Components for the Hand Glove Unit.

No.	Arduino Nano Pin	Input/Output Component
1.	D7, D8, D11, D12	Transceiver
2.	A4	Vibration Motor
3.	A0, A1, A2, A3, A7	Flex Sensor
4.	Vin, GND	9V Battery

In the mobile robot unit, two DC motors are connected to L298N 2A motor driver. The output voltage of Arduino Uno is not enough to power up the DC motors so motor driver is used. Another transceiver is connected to the Arduino Uno to receive signals from the hand glove unit so as to move the mobile robot accordingly.

Figure 3.4 shows the connection of all the components for mobile robot unit part. The transceiver is connected to the pins of Arduino Uno so that the signals can be received from the hand glove unit. The accelerometer is connected to the Arduino Uno so that the data collected from the mobile robot movement can be sent to the hand glove unit through transceiver. Two DC motors are connected to the motor driver so that the speed and direction of DC motors can be controlled.

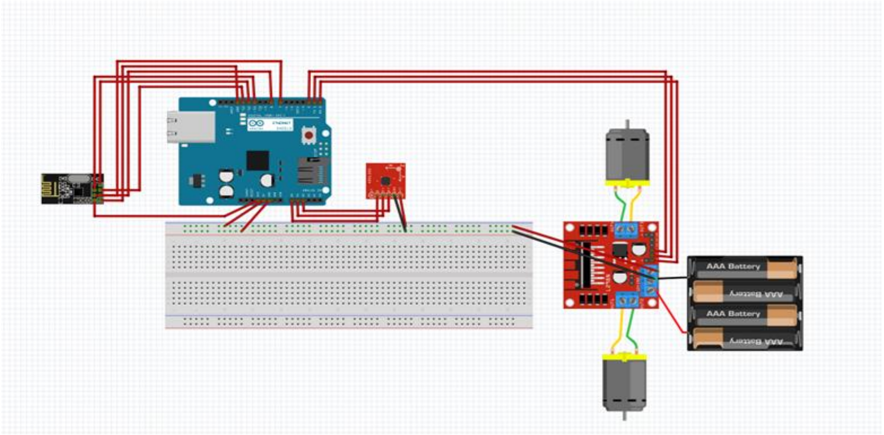


Figure 3.4: Schematic circuit of the mobile robot unit.

Table 3.2: Summary of Components for the Mobile Robot Unit.

No.	Arduino Uno Pin	Input/Output Components
1.	7, 8, 9, 11, 12	Transceiver
2.	0, 1	Accelerometer MPU6050
3.	2, 3, 4, 5, 9, 10	PWM Motor Driver

Table 3.3 shows the components that have been used to build the circuits for hand glove unit and mobile robot unit. The quantity of each component is listed out in the table so that it is easier to prepare while gathering all the components.

Table 3.3: List of Components for the Prototype's Hardware.

No.	Component Name	Quantity	Price per item (RM)	Total Price
1.	ADXL335 Accelerometer	1	10.00	10.00
2.	Flex sensor	5	49.00	245.00
3.	Arduino UNO	1	39.80	39.80
4.	nRF24L01 Transceiver module	1	11.90	23.80
5.	DC Motor	2	3.50	7.00
6.	Arduino Nano	1	24.90	24.90
7.	L298N 2A motor driver	1	5.40	5.40
8.	PWM vibration motor	1	5.50	5.50
9.	9V Battery	1	12.00	12.00
10.	Rechargeable AA Battery	3	4.00	12.00
11.	Casing	1	29.90	29.90
			Grand Total	**415.30**

3.2.2 Program Code Configuration

Based on Figure 3.5, the program code began with the flex sensors as input. The data collected from the flex sensors will be sent to the Arduino Uno of the mobile robot unit through transceiver. The vibration motor will provide haptic feedback by vibrating to notice the user whenever the mobile robot is moving. Also, accelerometer data from the mobile robot unit will be received through transceiver so the data will be stored at Arduino Nano.

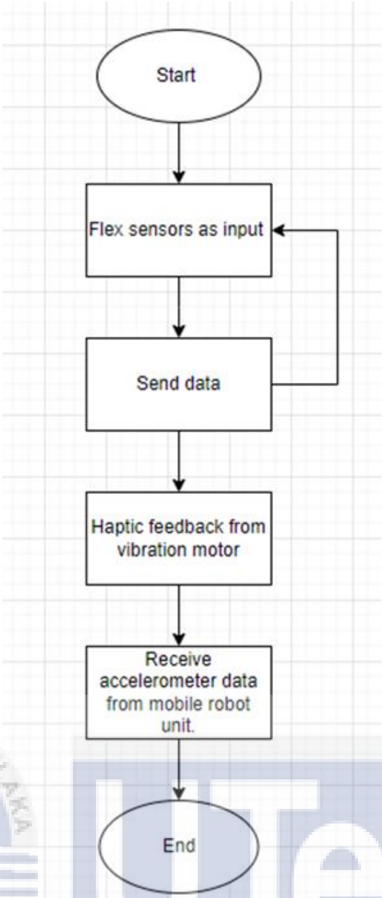
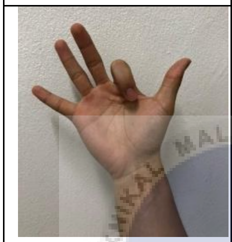
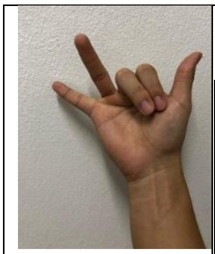
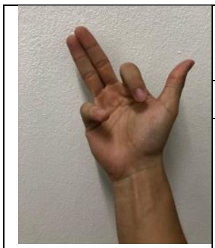


Figure 3.5: Program code flowchart of hand glove unit.

Table 3.4 shows the types of hand gestures which work as a command to the mobile robot movement. There are seven types of hand gestures to control the movement of mobile robot. Users could command the mobile robot accordingly so that the mobile robot moves as desired.

Table 3.4: Types of hand gestures.

Hand gestures	**Mobile robot movement**		**Flex Sensors (Analog Value)**				
 *Figure 3.6: Stop Hand Gesture*	Stop		F1	F2	F3	F4	F5
	Motor 1	Motor 2	217	183	202	222	193
	Off	Off					
 *Figure 3.7: Forward Hand Gesture*	Forward		F1	F2	F3	F4	F5
	Motor 1	Motor 2	314	175	358	355	334
	On (Clockwise)	On (Clockwise)					
 *Figure 3.8: Backward Hand Gesture*	Backward		F1	F2	F3	F4	F5
	Motor 1	Motor 2	355	339	363	242	338
	On (Counter-Clockwise)	On (Counter-Clockwise)					
 *Figure 3.9: Forward Right Hand Gesture*	Forward Right		F1	F2	F3	F4	F5
	Motor 1	Motor 2	339	197	222	358	339
	On (Clockwise)	On (Counter-Clockwise)					

 *Figure 3.10: Forward Left Hand Gesture*	Forward Left		F1	F2	F3	F4	F5
			335	206	372	364	300
	Motor 1	Motor 2					
	On (Counter-Clockwise)	On (Clockwise)					
 *Figure 3.11: Backward Right Hand Gesture*	Backward Right		F1	F2	F3	F4	F5
			365	344	225	265	340
	Motor 1	Motor 2					
	On (Clockwise)	On (Counter-Clockwise)					
 *Figure 3.12: Backward Left Hand Gesture*	Backward Left		F1	F2	F3	F4	F5
			372	217	368	236	231
	Motor 1	Motor 2					
	On (Counter-Clockwise)	On (Clockwise)					

Based on Figure 3.13, flex sensor data will be received through transceiver so Arduino Uno will evaluate the data whether the ADC value is greater than 300 or not. If the ADC value is greater than 300, the mobile robot movement will be executed, DC motors will be powered up. If the ADC value is not greater than 300, the process will return to reading the data of resistance value. Accelerometer will provide x,y, and z-axis reading of the mobile robot movement so the accelerometer data will be sent to hand glove unit data collecting purpose through transceiver.

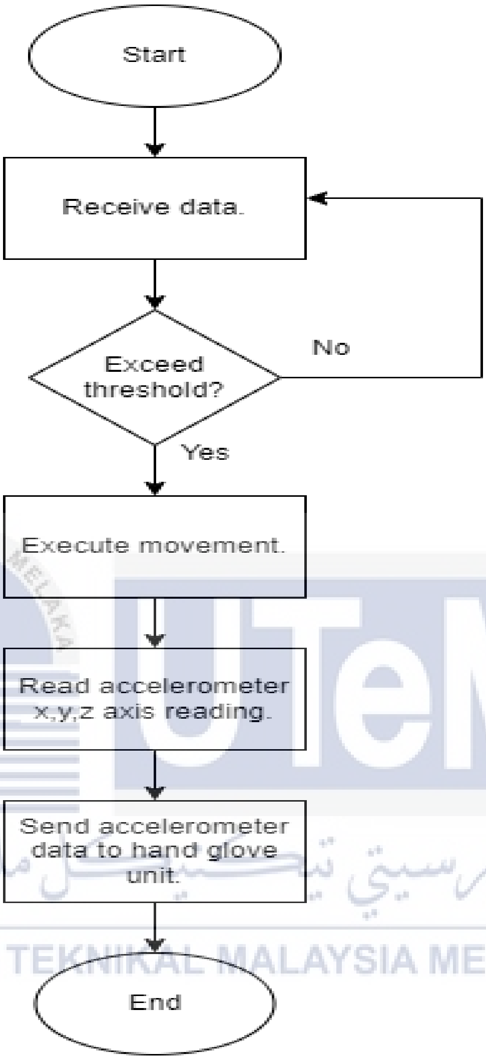


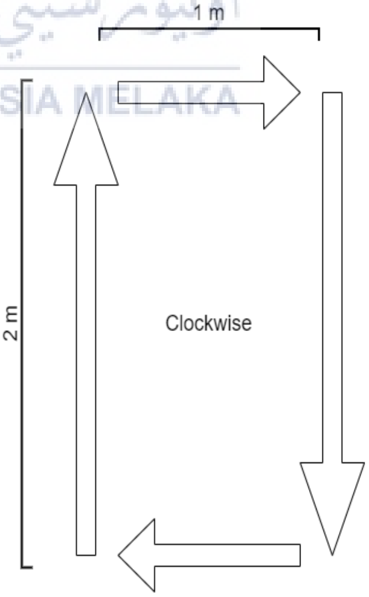
Figure 3.13: Program code flowchart of mobile robot unit.

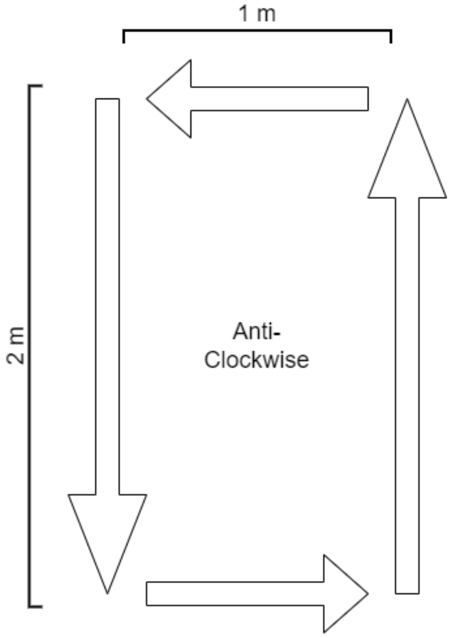
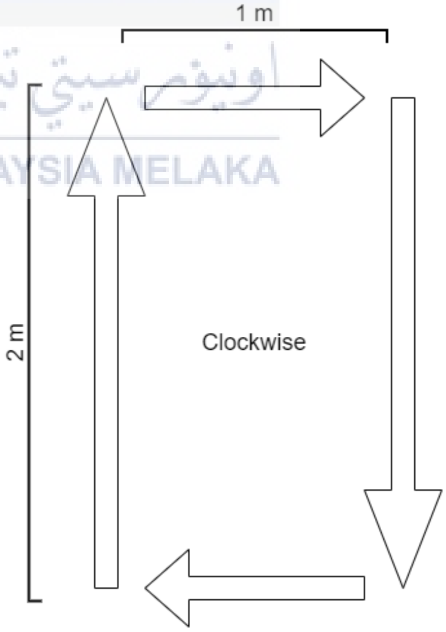
3.3 Demonstration of the Mobile Robot Movement in Different Environments

The prototype will be tested out in three different environments which are in ideal condition, on the lawn, and on the road. These three different environments are chosen to test the capabilities of the mobile robot movement being controlled by the haptic-based hand glove. By demonstrating the mobile robot's movement controlled by hand gesture signals using a hand glove in ideal conditions, on the lawn, and on the road, it showcases the robot's versatility and adaptability across different environments. The hand gesture control system adds an intuitive and user-friendly interface, enabling seamless interaction between the user and the robot. This demonstration allows for evaluating the accuracy, responsiveness, and effectiveness of the hand gesture control system in real-world scenarios.

The size of the space is set in between 50 meters of range to have a better connection between the hand glove unit and the mobile robot unit. The prototype will be tested with three turns in total on three different environments with about 2 meter square of surface area as shown in Figure 3.7, 3.8, and 3.9 to collect the reading of x,y,z.

Table 3.5: Different Environments for Mobile Robot Prototype Testing.

No.	Environments	Route/Track
1.	 *Figure 3.14: Ideal Condition.*	 *Figure 3.15: Route of Mobile Robot for Ideal Condition.*

No.	Environments	Route/Track
2.	 *Figure 3.16: On the Road.*	 Figure 3.17: Route of Mobile Robot on the Road.
3.	 *Figure 3.18: On the Lawn.*	 *Figure 3.19: Route of Mobile Robot on the Lawn.*

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Prototype of Haptic-Based Hand Glove and Mobile Robot

Figure 4.1 shows the prototype of hand glove unit. The hand glove unit is constructed with flex sensors, vibration motor, and transceiver connected to Arduino Nano. The flex sensors are placed on each finger of the hand glove so that the ADC value of each finger can be detected accurately.

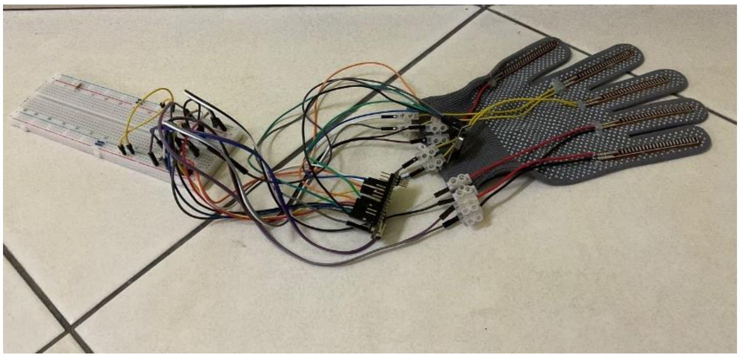


Figure 4.1: Hand Glove Unit Prototype.

Figure 4.2 shows the prototype of mobile robot unit. The mobile robot unit is constructed with accelerometer, transceiver, L298N motor driver, and DC motors connected to Arduino UNO. The mobile robot unit is powered up by 3 units of 3.7V battery connected to the L298N motor driver. The motor driver's output 5V is given to Arduino UNO.

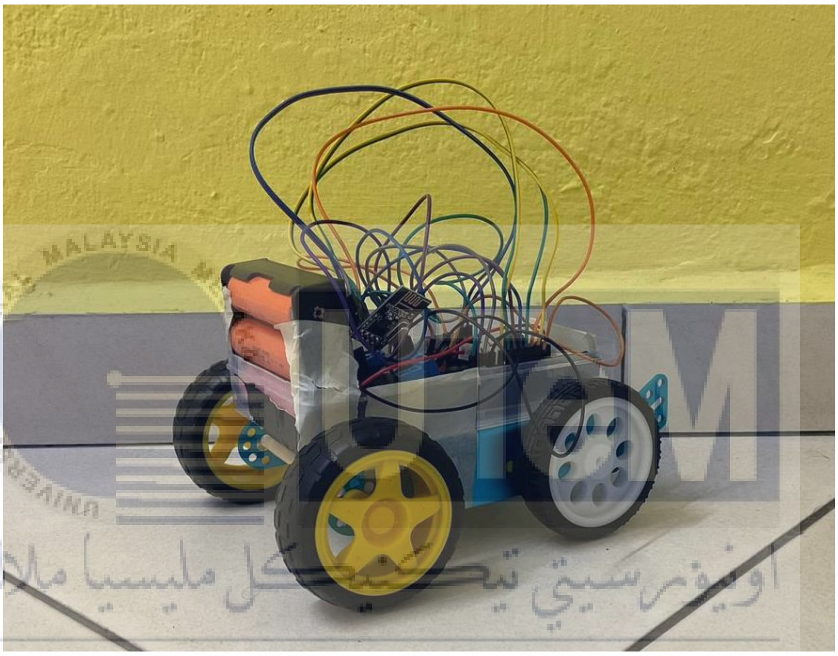


Figure 4.2: Mobile Robot Unit Prototype.

4.2 Analysis of Haptic-Based Hand Glove Unit

The analysis of haptic-based hand glove unit is done by collecting data from each flex sensor on the hand glove. There are 3 different users required to make 7 different hand gestures in the data collecting process. The data collected will analyzed according to each finger of the users.

Figure 4.3 shows the analysis graph of ADC value of the flex sensors for stop hand gesture. There are 5 graphs in the figure, each graph represents different fingers which are thumb, index finger, middle finger, ring finger, and little finger. There are 3 colours of lines on each graph which shows each colour represents a user. The yellow-coloured circle shows the differences on the graph. From the thumb's graph, there is a small difference on the ADC value from each user which shows that each user has different hand gestures on performing a stop hand gesture. This situation happens on the index finger's graph, there is a small difference on the ADC value of each user. The other fingers' graphs show almost the same.

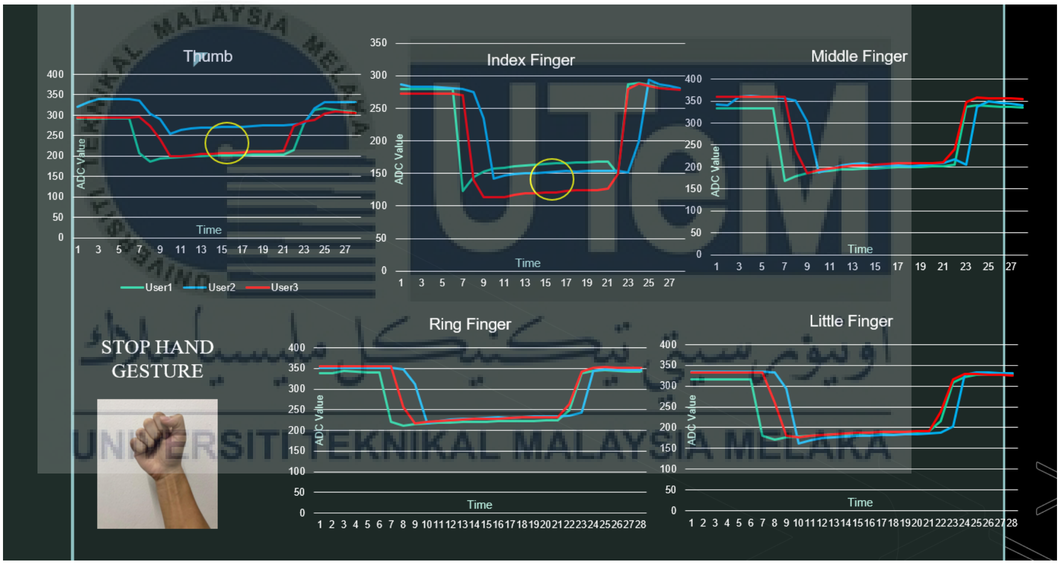


Figure 4.3: Analysis Graph of Stop Hand Gesture.

Figure 4.4 shows the analysis graph of ADC value of the flex sensors for forward hand gesture. There are 5 graphs in the figure, each graph represents different fingers which are thumb, index finger, middle finger, ring finger, and little finger. There are 3 colours of lines on each graph which shows each colour represents a user. From the 5 graphs, there are some fluctuations on thumb, ring finger, and little finger's graph.

This can be explained that each user will have their finger jittering while they are trying to hold the position of their fingers for some time.

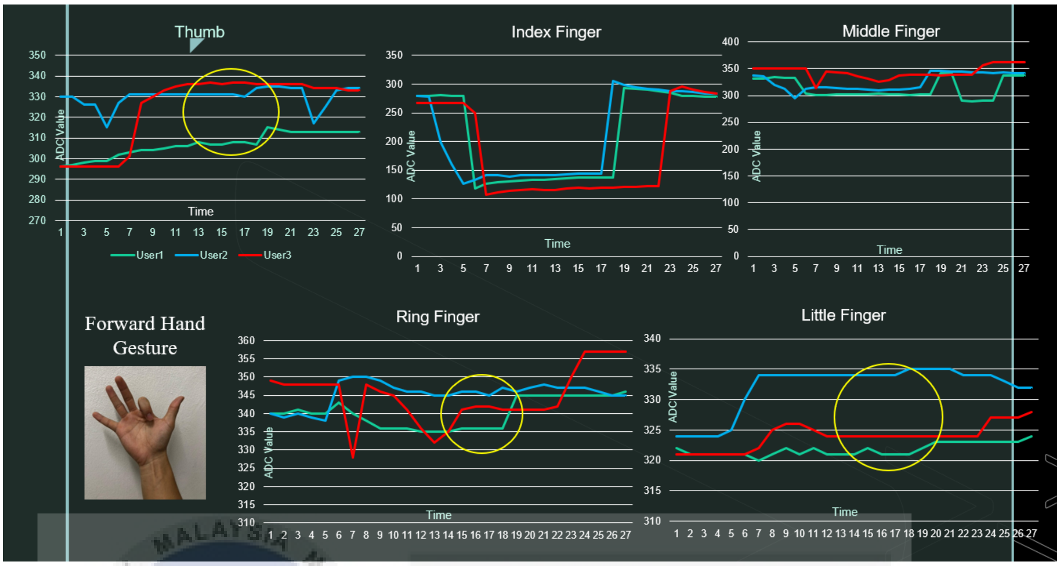


Figure 4.4: Analysis Graph of Forward Hand Gesture.

Figure 4.5 shows the analysis graph of ADC value of the flex sensors for backward hand gesture. There are 5 graphs in the figure, each graph represents different fingers which are thumb, index finger, middle finger, ring finger, and little finger. There are 3 colours of lines on each graph which shows each colour represents a user. From the 5 graphs, there are some fluctuations on thumb, index finger, middle finger, and little finger's graph. This can be explained that each user will have their finger jittering while they are trying to hold the position of their fingers for some time.

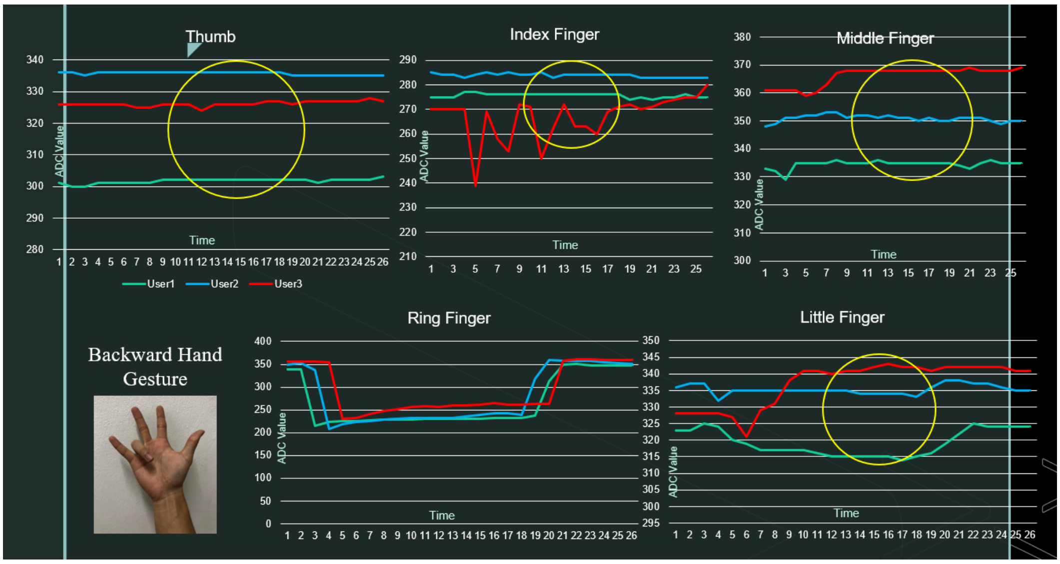


Figure 4.5: Analysis Graph of Backward Hand Gesture.

Figure 4.6 shows the analysis graph of ADC value of the flex sensors for forward right hand gesture. There are 5 graphs in the figure, each graph represents different fingers which are thumb, index finger, middle finger, ring finger, and little finger. There are 3 colours of lines on each graph which shows each colour represents a user. From the 5 graphs, there are some fluctuations on thumb and ring finger's graph. This can be explained that each user will have their finger jittering while they are trying to hold the position of their fingers for some time.

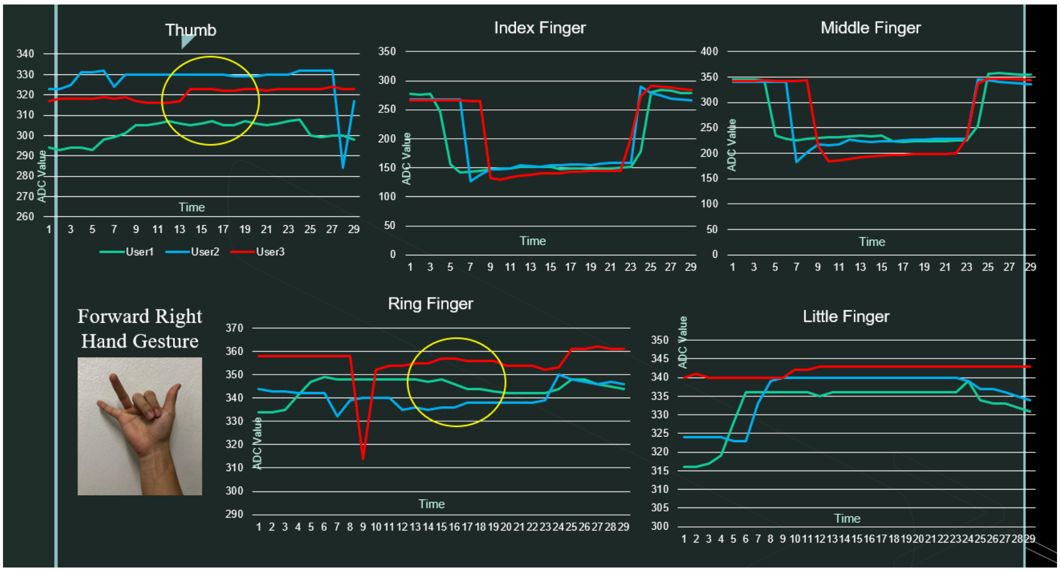


Figure 4.6: Analysis Graph of Forward Right Hand Gesture.

Figure 4.7 shows the analysis graph of ADC value of the flex sensors for forward left hand gesture. There are 5 graphs in the figure, each graph represents different fingers which are thumb, index finger, middle finger, ring finger, and little finger. There are 3 colours of lines on each graph which shows each colour represents a user. From the 5 graphs, there are some fluctuations on ring finger’s graph. This can be explained that each user will have their finger jittering while they are trying to hold the position of their fingers for some time.

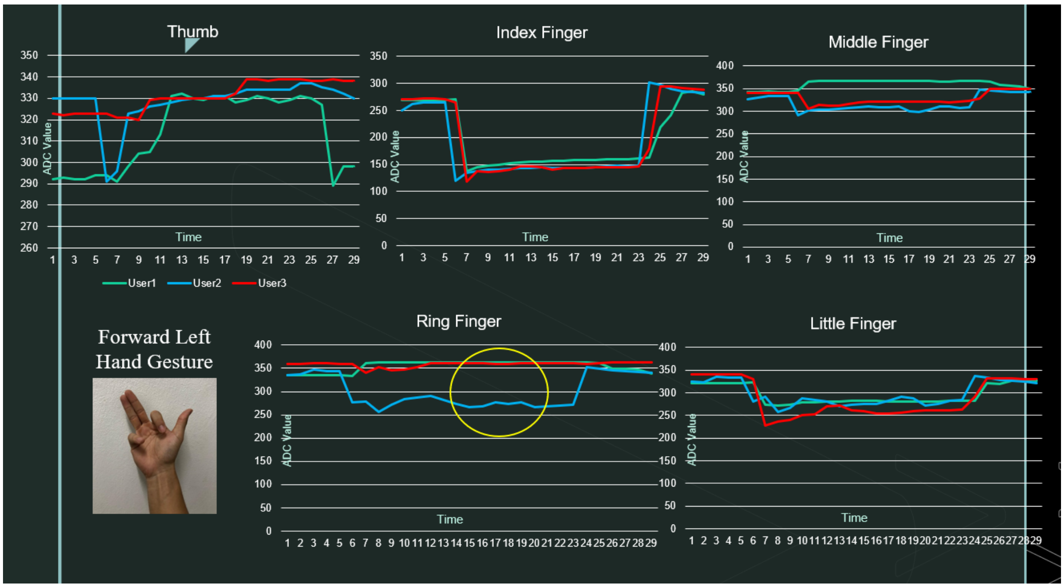


Figure 4.7: Analysis Graph of Forward Left Hand Gesture.

Figure 4.8 shows the analysis graph of ADC value of the flex sensors backward right hand gesture. There are 5 graphs in the figure, each graph represents different fingers which are thumb, index finger, middle finger, ring finger, and little finger. There are 3 colours of lines on each graph which shows each colour represents a user. From the 5 graphs, there are some fluctuations on thumb and little finger's graph. This can be explained that each user will have their finger jittering while they are trying to hold the position of their fingers for some time.

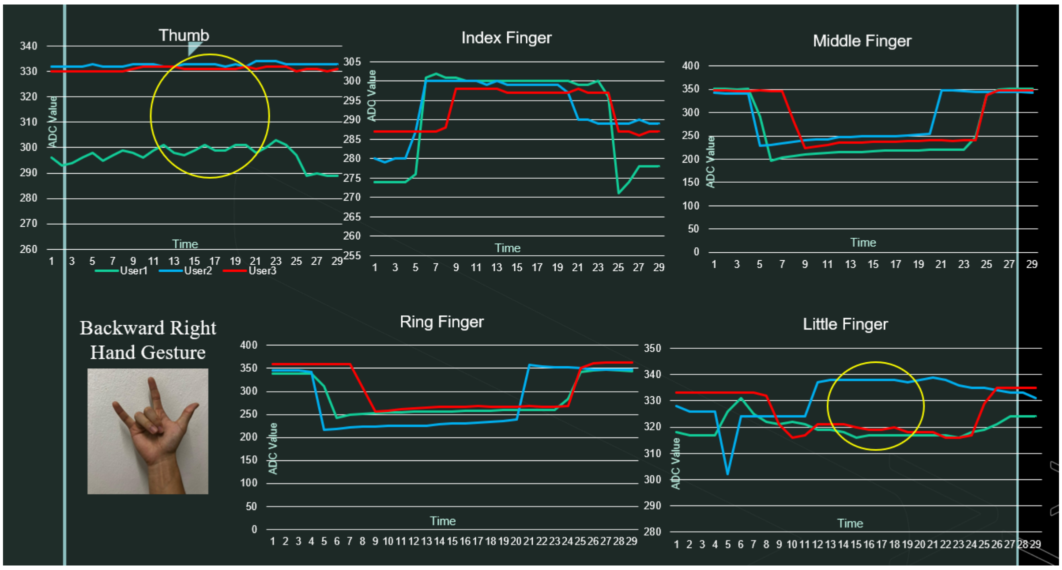


Figure 4.8: Analysis Graph of Backward Right Hand Gesture.

Figure 4.9 shows the analysis graph of ADC value of the flex sensors for backward left hand gesture. There are 5 graphs in the figure, each graph represents different fingers which are thumb, index finger, middle finger, ring finger, and little finger. There are 3 colours of lines on each graph which shows each colour represents a user. From the 5 graphs, there are some fluctuations on thumb index finger, and middle finger's graph. This can be explained that each user will have their finger jittering while they are trying to hold the position of their fingers for some time.

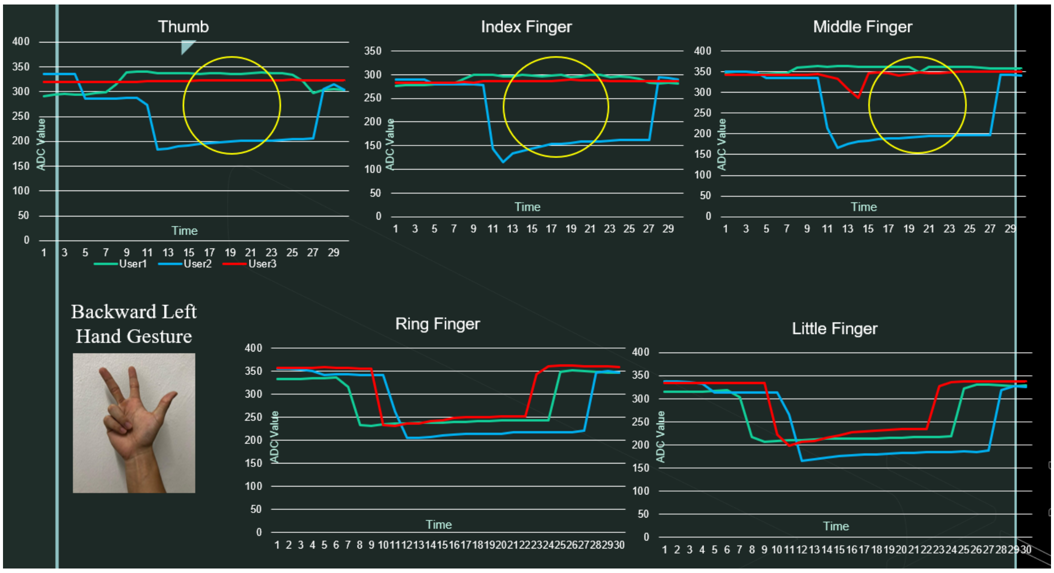


Figure 4.9: Analysis Graph of Backward Left Hand Gesture.

The analysis of haptic-based hand glove unit found out that the ADC values of flex sensors for each user are different. This means that the haptic-based hand glove unit should be personalized for each user so that the mobile robot unit can be controlled accordingly, and accuracy is confirmed.

4.3 Analysis of Mobile Robot Movement in 3 Different Environments

The analysis of mobile robot movement is done by collecting data from the accelerometer. The accelerometer reading will be collected while the mobile robot unit is moving with the control of haptic-based hand glove. The data collected will be analyzed to show the X, Y, and Z reading from the accelerometer. X shows the direction of forward and backward, Y shows the direction of left and right, while Z shows the direction of up and down.

Figure 4.10 shows the analysis graph of accelerometer reading when mobile robot unit is moving in ideal condition. There are 3 colours of line on the graph, blue colour is X reading, orange is Y reading while grey is Z reading. From the graph, X reading is increasing positively because the mobile robot unit is making a turn in clockwise condition. Y reading maintains the reading at range of 0-2. Z reading does not change much in this environment.

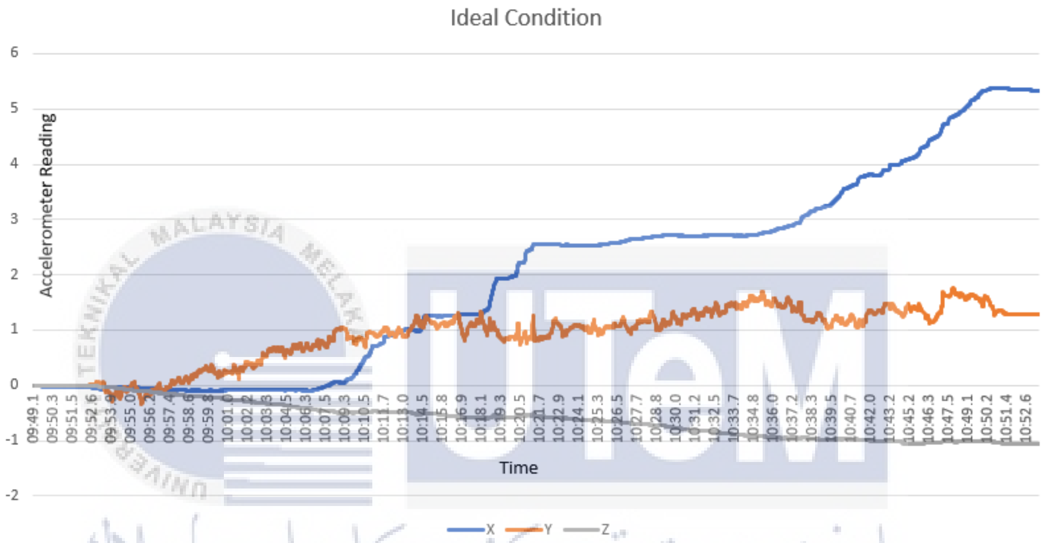


Figure 4.10: Analysis Graph of Accelerometer Reading When Prototype is Moving in Ideal Condition.

Figure 4.11 shows the analysis graph of accelerometer reading when mobile robot unit is moving on the road. From the graph, X reading is decreasing negatively because the mobile robot unit is making a turn in anti-clockwise condition. Y reading has a big fluctuation that can be seen on the graph, this is because the surface of the environment is not flat. Z reading does not have many changes.

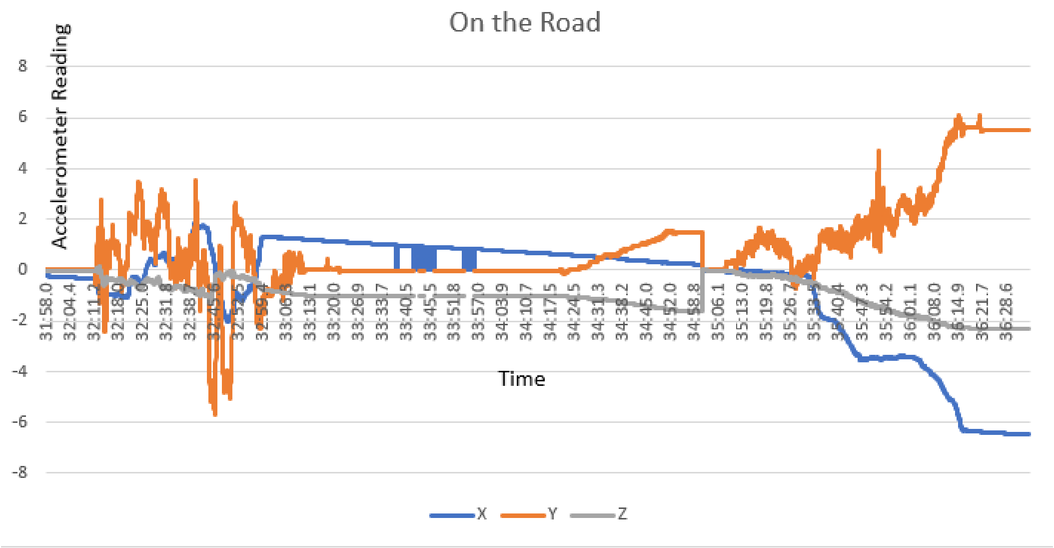


Figure 4.11: Analysis Graph of Accelerometer Reading When Prototype is Moving on the Road.

Figure 4.12 shows the analysis graph of accelerometer reading when mobile robot unit is making a turn on the lawn. From the graph, X reading is increasing positively because the mobile robot unit is making a turn in clockwise condition. Y reading has more fluctuations than the previous one, this is because the surface of the environment is totally not flat and there are some holes in it.

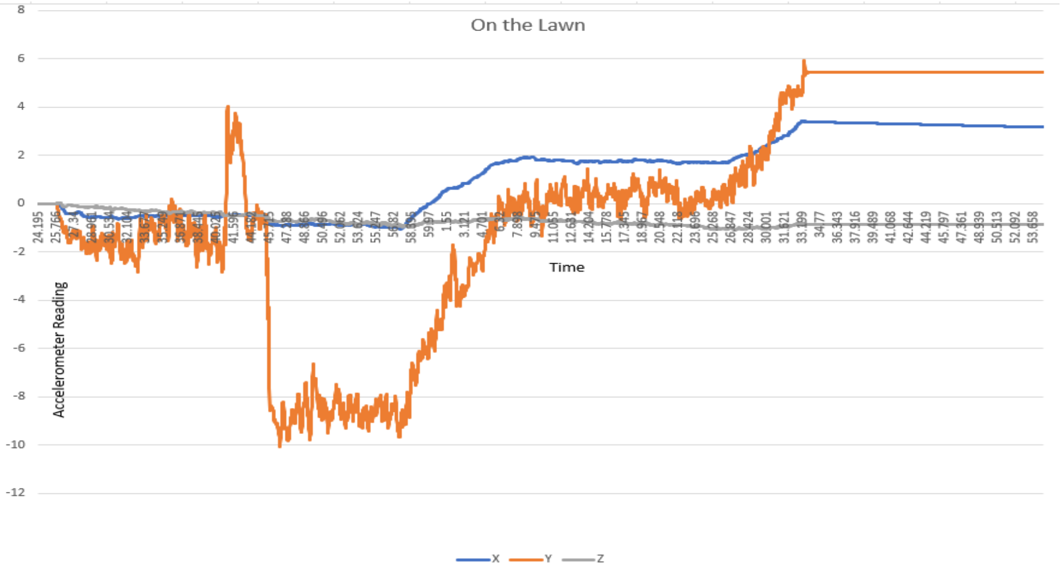


Figure 4.12: Analysis Graph of Accelerometer Reading When Prototype is Moving on the Lawn.

The analysis of mobile robot unit movement in 3 different environments found out that there are differences between the accelerometer X, Y, and Z reading of ideal condition, on the road, and on the lawn. Due to the lack of vision in enclosed space, user does not have information of the topography of the space, this analysis can be used as a reference for the mobile robot movement.

4.4 Environment and Sustainability of the System

The project, "Haptic-Based Personalized System Interface Using Hand Gesture Signals for Mobile Robot Movement," contributes to Sustainable Development Goal (SDG) 11: Sustainable Cities and Communities by enhancing technological accessibility and safety in urban environments. The haptic-based interface, designed for diverse users and adaptable to local cultures, promotes a safer and more user-friendly interaction with mobile robots, aligning with the goal of creating inclusive, resilient, and sustainable cities. This technology has the potential to optimize urban mobility, reduce risks of accidents, and improve the overall well-being of communities within city environments.

Figure 4.13: Sustainable Development Goal (SDG) 11: Sustainable Cities and Communities.

CHAPTER 5

CONCLUSION AND FUTURE WORKS

5.1 Conclusion

This project can be concluded as the development of a haptic-based hand glove that can translate hand gesture signal into several mobile robot movement instructions is achieved. A transceiver is implemented to transmit the ADC value of flex sensors to the mobile robot unit so that the mobile robot unit can move accordingly. A vibration motor is implemented to give haptic feedback to the user whenever a hand gesture is performed. Obtaining the accuracy of the translated instruction by demonstrating the mobile robot movement in different environments is also achieved. A transceiver is implemented to receive the hand gesture signal from the hand glove unit. Accelerometer is implemented on the mobile robot unit to obtain the X, Y, and Z reading when the mobile robot unit is moving in different environments. This project can be concluded that the successful development of a haptic-based hand glove translating gesture signals into mobile robot movements, coupled with demonstrated accuracy across various environments, marks a significant advancement in intuitive human-robot interaction. This achievement lays the groundwork for future refinements, promising a more accessible and versatile era in robotics.

5.2 Future Work

Moving forward, enhancing the communication capabilities of the project is imperative for a more seamless and efficient user experience. The current implementation utilizes half-duplex transceivers, limiting the bidirectional communication flow. To address this constraint, future work should focus on transitioning to full-duplex transceivers. This advancement will not only enable simultaneous transmission and reception, eliminating potential delays in communication, but also enhance the overall responsiveness and real-time interaction between the haptic glove and the mobile robot. The integration of full-duplex transceivers stands as a logical next step to further optimize the performance and reliability of the developed haptic-based interface, ensuring its effectiveness across a broader range of applications and scenarios.

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APPENDICES

APPENDIX A HAND GLOVE UNIT PROGRAM CODE

```
#include <SPI.h>
#include <nRF24L01.h>
#include <RF24.h>


RF24 radio(7, 8); // CE, CSN

const int flexPin = A0;      // Pin connected to voltage divider
output
const int flexPin1 = A1;
const int flexPin2 = A2;
const int flexPin3 = A3;
const int flexPin4 = A7;


int data[5];

const byte address[6] = "00001";
float Rflex0 = 0;
float Rflex1 = 0;
float Rflex2 = 0;
float Rflex3 = 0;
float Rflex4 = 0;

void setup() {
  Serial.begin(9600);
  pinMode(flexPin, INPUT);
  pinMode(flexPin1, INPUT);
  pinMode(flexPin2, INPUT);
  pinMode(flexPin3, INPUT);
  pinMode(flexPin4, INPUT);

  pinMode(4, OUTPUT);

  radio.begin();
```

```
  radio.openWritingPipe(address);
  radio.setPALevel(RF24_PA_MIN);
  radio.stopListening();
}

void loop() {

  Rflex0 = analogRead(flexPin);
  Rflex1 = analogRead(flexPin1);
  Rflex2 = analogRead(flexPin2);
  Rflex3 = analogRead(flexPin3);
  Rflex4 = analogRead(flexPin4);


  data[0] = Rflex0;
  data[1] = Rflex1;
  data[2] = Rflex2;
  data[3] = Rflex3;
  data[4] = Rflex4;


  for(int i=0;i<5;i++){
    Serial.println(data[i]);
    }


 bool success = radio.write(&data, sizeof(data));

  if (success) {
    if(Rflex1< 300 | Rflex3< 300){
      digitalWrite(4, HIGH);
      }else{
        digitalWrite(4, LOW);
      };
    Serial.println("Array transmitted successfully!");
  } else {
    Serial.println("Failed to transmit array.");
  }



  delay(500);
}
```

APPENDIX B MOBILE ROBOT UNIT PROGRAM CODE

```
#include <SPI.h>
#include <nRF24L01.h>
#include <RF24.h>


RF24 radio(7, 8); // CE, CSN

const float VCC = 5;
const float R_DIV = 15000.0;
const float flatResistance = 11800.0;
const float bendResistance = 22000.0;

const byte address[6] = "00001";

float Rflex0;
float Rflex1;
float Rflex2;
float Rflex3;
float Rflex4;

const int ENA = 5;
const int IN1 = 4;
const int IN2 = 2;
const int ENB = 3;
const int IN3 = 10;
const int IN4 = 9;

int receivedData[5];


float x =0;
float y =0;
float z =0;

void setup() {
  Serial.begin(9600);



  radio.begin();
  radio.openReadingPipe(1, address);
  radio.setPALevel(RF24_PA_HIGH);
  radio.startListening();

  pinMode(ENA, OUTPUT);
  pinMode(IN1, OUTPUT);
```

```
  pinMode(IN2, OUTPUT);
  pinMode(ENB, OUTPUT);
  pinMode(IN3, OUTPUT);
  pinMode(IN4, OUTPUT);
}

void loop() {
  if (radio.available()) {
    radio.read(&receivedData, sizeof(receivedData));
    Serial.println("Array received:");
  }

  Rflex0 = receivedData[0];
  Rflex1 = receivedData[1];
  Rflex2 = receivedData[2];
  Rflex3 = receivedData[3];
  Rflex4 = receivedData[4];

  if (Rflex1<200){
    if(Rflex0>200&Rflex2>200&Rflex3>200&Rflex4>200)     //forward
    {
      digitalWrite(ENA, 50);
      digitalWrite(IN1, HIGH);
      digitalWrite(IN2, LOW);
      analogWrite(ENB, 50);
      digitalWrite(IN3, LOW);
      digitalWrite(IN4, HIGH);
    }else if(Rflex0>300&Rflex2>300&Rflex3>300&Rflex4<300)    //FL
    {
      digitalWrite(ENA, 0);
      digitalWrite(IN1, HIGH);
      digitalWrite(IN2, LOW);
      analogWrite(ENB, 50);
      digitalWrite(IN3, LOW);
      digitalWrite(IN4, HIGH);
    }else if(Rflex0>300&Rflex2<300&Rflex3>300&Rflex4>300)    //FR
    {
      digitalWrite(ENA, 50);
      digitalWrite(IN1, HIGH);
      digitalWrite(IN2, LOW);
      analogWrite(ENB, 0);
      digitalWrite(IN3, LOW);
      digitalWrite(IN4, HIGH);
      }
  }else if(Rflex3<300){
    if(Rflex0>300&Rflex1>200&Rflex2>300&Rflex4>300)     //Backward
    {
      digitalWrite(ENA, 50);
```

```
      digitalWrite(IN1, LOW);
      digitalWrite(IN2, HIGH);
      analogWrite(ENB, 50);
      digitalWrite(IN3, HIGH);
      digitalWrite(IN4, LOW);
    }else if(Rflex0>300&Rflex1>200&Rflex2>300&Rflex4<300)    //BL
    {
      digitalWrite(ENA, 0);
      digitalWrite(IN1, LOW);
      digitalWrite(IN2, HIGH);
      analogWrite(ENB, 200);
      digitalWrite(IN3, HIGH);
      digitalWrite(IN4, LOW);
    }else if(Rflex0>300&Rflex1>200&Rflex2<300&Rflex4>300)    //BR
    {
      digitalWrite(ENA, 100);
      digitalWrite(IN1, LOW);
      digitalWrite(IN2, HIGH);
      analogWrite(ENB, 0);
      digitalWrite(IN3, HIGH);
      digitalWrite(IN4, LOW);
      }
    }else{
    digitalWrite(ENA, 0);
    digitalWrite(IN1, HIGH);
    digitalWrite(IN2, LOW);
    analogWrite(ENB, 0);
    digitalWrite(IN3, LOW);
    digitalWrite(IN4, HIGH);
    }

  delay(300);
}
```