The University of Manchester

Design a Haptic Feedback Unit for Blind People to Interface with a Quadrature Robot Guide Dog

Third Year Individual Project – Final Report

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Abstract

This paper presents the design and test of a portable haptic feedback unit that interfaces with a robot guiding dog to guide blind people. The feedback unit connects to the robot dog and tracks its movements using an Infrared positioning camera. It then uses a 1-DOF slider mechanism with a slot for the thumb finger to rest on that acts like a compass pointing in the direction of the robot. Additionally, the unit incorporates a set of vibration motors that provide guidance cues to the user. The experimental results demonstrate that the feedback unit can successfully track and measure the distance between the user and the robot, and provides different vibration patterns for the user to follow.

Declaration of originality

I hereby confirm that this dissertation is my own original work unless referenced clearly to the contrary, and that no portion of the work referred to in the dissertation has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

Intellectual property statement

1 Introduction

1.1 Background and motivation

With the development of modern technology, there is a continuous increase in the tasks that robots can perform to help people improve their daily lives. Starting with collaborative robots in factories and many other workspaces functioning alongside workers to help boost productivity while reducing accidents by performing dangerous and difficult tasks that may require high precision [1]. Robots are also used in healthcare and services sectors where domestic robots, also known as personal service robots, are often used to perform a wide range of tasks to help the elderly and individuals with disabilities, from cleaning to providing companionship and care [2], [3].

People affected by visual impairment and other visual disorders need assistance to complete some daily tasks, such as navigating safely, specially while exploring unfamiliar environments. According to the World Health Organization's recent statistics, the number of visually impaired people with moderate or severe distance vision around the world is approximately 1 billion, of which 217 million people have a slight vision, while 43 million are completely blind [4]. As the population grows and the number of elderly rises, the risk of more individuals becoming visually impaired increases [4].

Being blind or visually impaired does not necessarily mean losing the accessibility of getting to places whenever needed [5]. The visually impaired can travel independently by their own convenient means daily. However, there are several challenges that need to be overcome in order to reach the desired destination safely [6], such as locating pits in front of the path, stairs, traffic junctions, wet floors indoors and greased or slippery outdoor paths. Some of the commonly used tools and frameworks that help the visually impaired navigate are white canes and guide dogs [5]. As a result, constant efforts have been made by researchers to develop tools and equipment to assist the visually impaired to navigate freely and move through different environments and conditions effortlessly.

There is no doubt that guide dogs play a vital role in helping the visually impaired navigate and explore their surroundings. They are more favourable as they provide feedback and companionship to the owner, as well as providing mental and emotional support to some blind people. However, guide dogs require extensive training that can last more than seven weeks, and their skills cannot be transferred to each other. Additionally, they can be very expensive and have an average working life of eight years [7], [8]. As autonomous robot technology is getting more advanced over time, there have always been many attempts to make effective use of these new capabilities to help blind people and give them a better sense of their environment. Moreover, try to close the gap of lack of assistive tools for the blind, where the current tools are considerably basic when compared to modern technology in other sectors [9].

Robots equipped with lidars and many other perception modules can map their environment and provide detailed information about their surroundings. The collected data can then be processed to allow these robots to navigate autonomously [10]. Such robots can be used to guide blind people; however, the main issue revolves around how to convert the sensory information to the users allowing them to navigate efficacy while facilitating communication between them.

1.2 Aims and objectives

The aim of this project is to design and develop a haptic feedback unit that interfaces with a robot guide dog to help the blind navigate their surroundings.

The following objectives were formulated to achieve the overall aim of the project:

- Investigate and compare different haptic feedback designs to decide the most suitable design approach for this application.
- Design and test a haptic feedback mechanism to provide input to the user.
- Design an infrared-based positioning system to keep track of the robot movements.
- Identify and implement a suitable communication means between the robot and the feedback unit.
- Simulating the robot using Gazebo robotics simulator.

1.3 Feedback Unit Design Specifications

The haptic feedback unit is designed to provide a tactile guiding experience for users during their interactions with the robot guide dog. It is built with a focus on mechanical and electrical requirements to ensure optimal performance and safety. The specifications cover various aspects, including the feedback unit's mechanical structure, safety features, and electrical specifications as detailed below.

Mechanical requirements

1. Structure
    - The feedback unit shall be no more than 180 g.
    - The unit shall fit comfortably in the palm of the user's hand, allowing for easy access to its features.
    - The unit shall provide tactile feedback to the user.
    - The vibration motors shall be isolated from each other to prevent vibrations from one motor affecting other parts of the unit.
    - The slider mechanism shall be rigid to withstand the continuous pressing (contact).
2. Safety
    - The unit shall not have any sharp edges.

Electrical requirements

3. General features
    - The wireless communication module shall have a minimum range of 3 meters.
    - The unit shall have a positioning system to provide a reference to the world frame.
4. Safety
    - The unit shall have a powering circuit to provide electrical protection to the microcontroller.

The feedback unit will be designed based on an adult right-handed male with an average hand size hand length and breadth of 19.02 ± 0.08 cm and 8.58 ± 0.03 cm respectively [11].

2 Literature review

In recent years, there has been a significant focus on designing assistive technologies to help visually impaired people navigate their surroundings [12]. Feedback units are considered an important form of assistive technology as they provide sensory information to the user, which can help them navigate their environment and perform daily activities more independently. In the context of guiding the blind, feedback refers to providing blind people with spatial information that enables them to perceive their surroundings. It should convey information related to the tasks to be understood by the user [13], [14]. The design of the feedback unit that connects to the guiding robot will have a great impact on the quality of the data provided to the user [12].

2.1 Types of Feedback Units for Visually Impaired Navigation

Generally, feedback units fall into three main categories: visual feedback, auditory feedback [15] and tactile feedback [5]. Visual feedback that mainly focuses on providing information through visual display is not suitable in applications for visually impaired people.

Auditory feedback uses sound to convey information to the user. This can be in the form of speech, music, or other sounds. Audio feedback can be effective in conveying complex information about the surroundings and helping identify specific locations or objects. Furthermore, it can also be used to provide directional information and instructions for navigating indoor and outdoor environments, as well as providing alerts for specific landmarks or features. Another advantage of using audio when guiding visually impaired people as it improves spatial awareness by providing more detailed descriptions and instructions [15].

An example of auditory feedback is GPS-based navigation, where a feedback unit uses GPS technology to provide the user with directional information, such as direction, distance and points of interest, using audible cues [16].

There are some downsides to using auditory feedback as it can be noisy and distracting, making it challenging for the user to hear other surrounding sounds and pay attention to their environment. Audio-based feedback can also have some inaccuracies as it can be affected by the quality of the speaker, the background noise and the individual's hearing abilities, making it inadequate for deaf users.

On the other hand, tactile or haptic feedback involves the use of vibrations or pressure to communicate information to the user. The sense of touch is a suitable means of providing this type of kinaesthetic information, as tactile signals can convey direction, magnitude and time efficiently. Additionally, tactile signals become easier to process than auditory signals when the user's attention is divided between multiple inputs [17].

Haptic feedback units come in many sizes and shapes, depending on the intended use and functionality. For example, handheld and wearable devices are often used as guiding devices, allowing more freedom of motion. However, providing compelling directional information can be challenging with handheld and wearable devices because they lack a reliable reference for positioning in the world coordinate frame [17]. Therefore, it is important that the feedback unit is equipped with sensors that can accurately sense and interpret the user's movements and orientation in the environment workspace.

2.2 Wearable haptic devices

Tactile belts are an example of wearable haptic feedback devices that are designed to provide tactile stimuli to the user's waist or torso. These belts have a series of small vibration motors that can be controlled to provide directional cues based on the user's movements and orientation. A tactile belt containing eight vibrating motors was used to guide blind people around a track using vibration patterns [18]. Figure 1 below illustrates the placement of the vibration motors around the user’s waist. the motors vibrate in the direction in which the user is intended to follow. The study analysed different vibration patterns to determine the most intuitive pattern that can be used to transmit directional information [18]. It was found that the single bursts can be better than sequence vibration patterns while guiding blind people and the guiding process could be improved with suitable training for using the tactile belt.

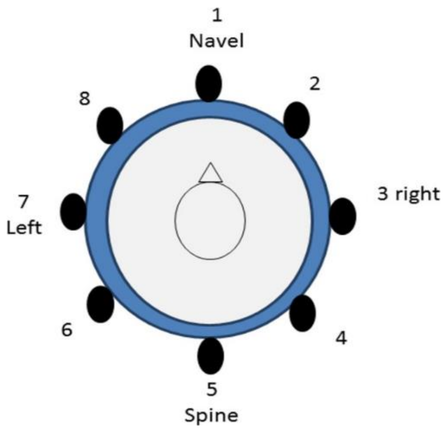


Fig. 1. Position of the vibration motors (top view) [18].

Haptic sleeves are another example of wearable haptic devices. These sleeves operate with 3D cameras to provide a multidimensional tactile experience [19]. The presented system uses distance information provided by dual infrared cameras integrated into a pair of goggles to generate a three-dimensional stereoscopic image of the environment in front of the user. This visual input is then translated into haptic feedback using a small computer, which maps the image onto the user's forearm using a 5 x 5 array of pads pressed against the user's forearm as shown in Figure 2 below. In functionality tests, users were able to accurately identify and localize both single-motor vibration patterns and multidirectional multi-motor vibration patterns [19].

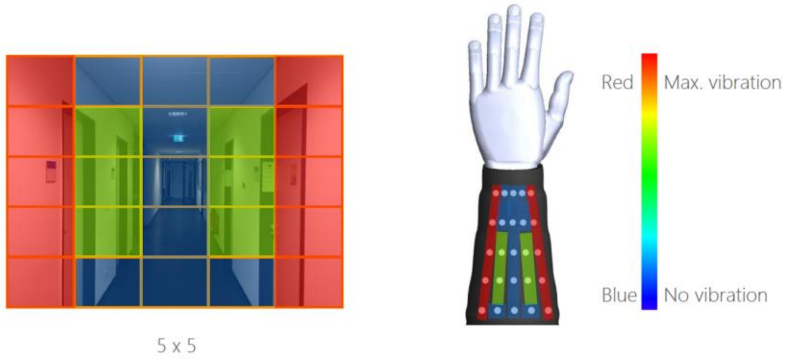


Fig. 2. Results of mapping the hallway on the haptic sleeve [19].

The haptic feedback sleeve design was found to have some limitations. For example, vibrations were found to be more difficult to recognize over non-muscular regions of the forearm, and the distance between the motors was too small causing the motor vibrations to be difficult to distinguish. Additionally, some time was required to adapt to the use of haptic feedback sleeves due to the unusual approach of providing direction and distance information using vibrations on the forearm [19].

2.3 Handheld Haptic Devices

Various studies have explored the use of handheld haptic devices in diverse fields such as gaming, virtual reality, rehabilitation, and navigation [20], [21]. Handheld haptic feedback devices can provide more compelling tactile sensations to the user compared to many wearable haptic devices as the reaction forces produced by the device can be spread over a larger area of skin far away from the stimulation point of contact [17]. Each of the following research papers [17], [21], [22]and [23] investigated a different type of haptic cue, its effectiveness, and its impact on user performance and satisfaction.

2.3.1 Holdable Haptic Device for 4-DOF Motion Guidance

The 4-DOF haptic device is one of the most relatable designs that can be used for haptic feedback and guidance in applications [17]. This hand-held kinaesthetic gripper was designed to provide guidance cues in four degrees of freedom (DOF) through 2-DOF tangential forces applied to the thumb and index finger. These cues can be used to translate or rotate the hand providing directional information to the user. Figure 3 below demonstrates the different parts of the 4-DOF device to give a better understanding of its functionality.

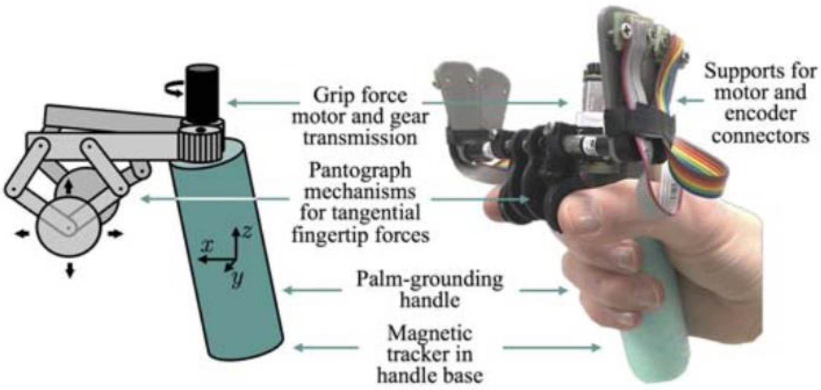


Fig. 3. Four-DOF Holdable Haptic Device [17].

This handheld haptic feedback device has several advantages. Firstly, it can provide intuitive guidance in four degrees of freedom without the need for external grounding, making it highly portable and adaptable to different environments. Furthermore, the cues used in the device do not require extensive training and can easily produce motion in different directions, making it user-friendly to be used in various applications.

On the other hand, there are some potential limitations to consider. One limitation is the technical complexity of the pantograph-five bar-linkage mechanism used in the device. This mechanism, along with the variability between users, as different individuals may perceive the haptic cues differently and exhibit varying hand and wrist kinematics. This may require customization or adaptation of the cues for each user.

Table 1 presents a design evaluation comparing two haptic feedback devices. The first device is the 4-DOF handheld haptic feedback device [17]. The second device is the Haptic feedback unit designed to interface with a robot guiding dog to guide blind people.

Table 1. Hand-held Haptic Feedback Devices Comparison.

Criteria	**4 DOF Haptic feedback device**	**Designed Haptic Feedback Unit**
Mechanical Complexity	Relatively High	Moderate
World reference (Tracking System)	An Ascension Trak Star 6-DOF magnetic tracking system.	IR Positioning camera tracking a robot guide dog.
Feedback Sources	Haptic cues via pantograph-five bar-linkage mechanism.	- Haptic cues via a slider mechanism. - Vibration motors. - Buzzer.
Cost	Higher cost due to pantograph-five bar-linkage mechanism and the tracking system.	Lower cost with single slider mechanism and an IR camera
Complexity of Operation	Intuitive Some adaptation and training may be required	Intuitive less training may be required

3 Methods

A critical issue faced by visually impaired people is navigating their daily surroundings easily and safely. For many years, guide dogs have been trained to assist individuals with vision impairment to address this problem. However, as getting a guide dog might not be a suitable option for everyone either due to its cost or availability, there was a need to find alternative options that facilitate their lives [8]. As a result of exploring different options, robot dogs were found to have the potential to serve as a suitable alternative to traditional guide dogs in assisting the blind. These robots were considered capable of providing the necessary functionality to help blind people navigate their surroundings with more ease and safety [24].

3.1 Robot Selection

A quadruped robot was chosen to be the mobile platform for this application as it has several advantages when compared to a typical wheeled robot, such as improving mobility as quadruped robots have a greater ability to navigate on uneven terrains, stairs and other obstacles [25].

Quadruped robots also have more degrees of freedom which allows them to perform more natural moves as well as mimicking the movements of living animals, therefore, they can navigate in complex environments more easily than other types of robots [26], which can be beneficial in helping blind people navigate in challenging environments. The Unitree A1 quadruped robot designed by unitree robotics was the starting choice due to its stability, dynamic movement capabilities and its high level of customizability that allows the addition of external devices and sensors.

In order to make substantial use of the robot's capabilities, a haptic feedback unit was designed to convey directional and sensory information as detailed in the next section (3.2).

3.2 Feedback Unit Design

A handheld portable design was chosen to be the main design for this application. The feedback unit was chosen to be wireless instead of having a leash to maintain a physical separation between the user and the robot to minimise the risk to the user in case of robot failure.

Using a leash for the robot to guide the user may not provide the blind person with enough information about the robot's movements, especially when the robot rotates or moves backwards. Furthermore, a leash can limit the dog's ability to move and navigate effectively. A robotic dog could be designed to move more freely and dynamically without a leash, allowing it to better assist blind people in navigating complex environments.

The feedback unit was designed to provide compelling guidance cues by applying tangential force on the thumb finger in a single degree of freedom (1-DOF) and grounding the reaction forces through the handle of the unit.

The concept is to make a slider that moves horizontally with a groove for the thumb to rest on (will be referred to as Thumb pad). The slider will act like a compass always pointing in the direction of the guiding robot. The feedback unit features an IR positioning camera that detects an IR LED bar mounted on the back of the guiding robot dog.

An Arduino Nano 33 IOT is used as the main microcontroller for the haptic feedback unit due to its small size factor and low power consumption. It also features a built-in Bluetooth module that can be used to communicate with other devices [27].

The Arduino Nano is used to process the IR camera data for controlling the thumb pad slider mechanism using a servo motor. It also connects wirelessly to another Arduino Uno WiFi Rev2 board connected serially to the robot dog via USB to acquire the directional information of the dog's movement. Once the data is received by the Arduino Nano, a set of vibration motors is controlled to produce a certain pattern to provide haptic cues to the user's finger tips indicating the robot's moving direction. The flowchart in Figure 4 illustrates the overall system and how all the components connect together.

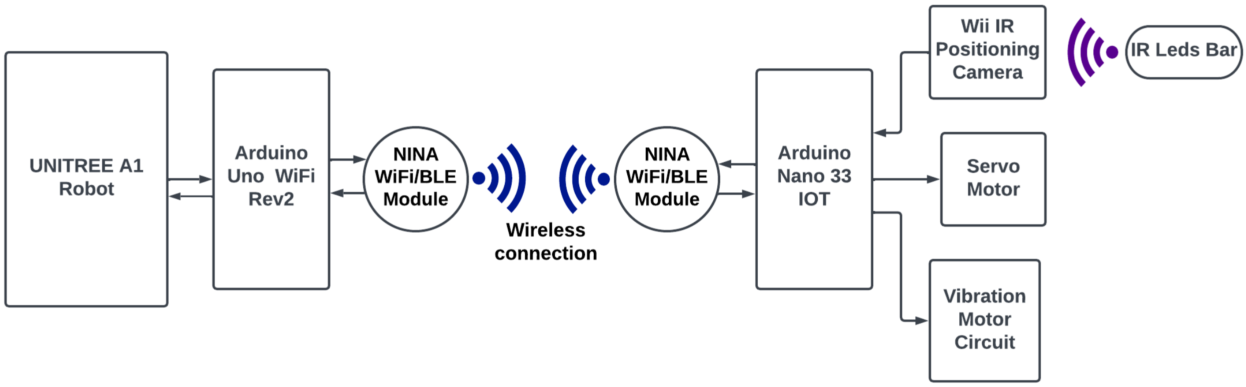


Fig. 4. Flowchart of the Feedback System Structure.

In order to produce the tangential force on the thumb finger, different mechanisms were considered, modelled and then tested using a cloud-based 3D computer-aided design (CAD) software (Fusion 360) to choose a suitable mechanism that can introduce the required range of motion while being compact to fit in the handheld unit.

According to the American Association for Hand Surgery [28], the radial abduction angle of the thumb is 62.9 ± 4.3° with a range of (53°-71°). In other words, when the thumb finger moves away from the palm, the angle it makes with the rest of the fingers is usually around 62.9°, but it can vary between 53° and 71° in different people. This range of motion when taken into account along the average thumb length of 64 mm [29], the maximum length of the slider track was calculated to be 114 mm. A shorter length for the slider track was chosen to be around 70 mm based on testing so that it can be suitable for users with different thumb lengths. Additionally, the distance the slider can travel on the track can be controlled via software, making it more flexible and customizable for individual users.

3.2.1 Comparing Design Mechanisms

Two main mechanisms were designed and compared to achieve the required slider horizontal motion. Figure 5 below shows the CAD model of the first mechanism. It consists of a link attached to the output shaft of a servo motor. As the servo motor shaft rotates, the link is also rotated along an arc-shaped path of a length of 73.7 mm so that the travelled horizontal distance will be about 66.8 mm.

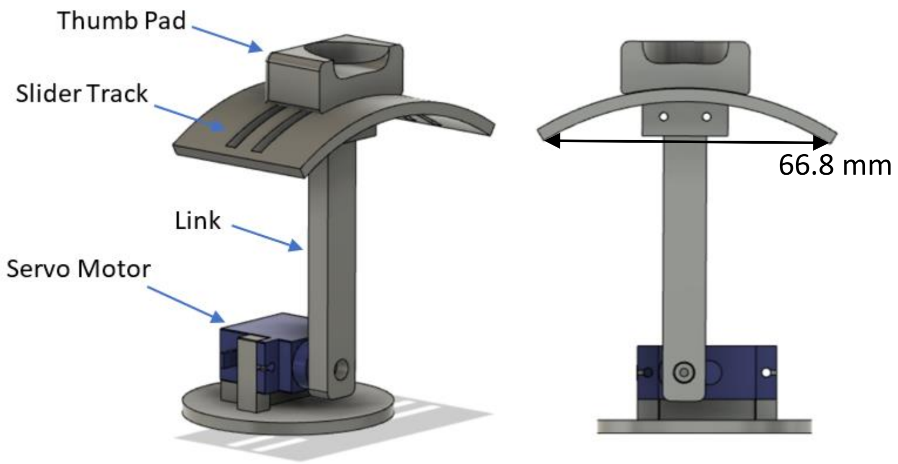


Fig. 5. CAD Model of the First Slider Mechanism.

The problem with this design is that in order to get a straighter arc, the link should be longer (around 62 mm in this design) and therefore, the mechanism will take a relatively large space inside the unit, making it harder to place other components inside the unit without increasing the overall size of the unit. Additionally, the longer the link, the higher torque needed from the servo motor to deliver sufficient force to move the thumb finger in the required direction.

The second mechanism consists of a link connected to a servo motor from one end, and to an inner slider rail from the other end. the inner slider itself is connected to a thumb pad that slides on the outer slider to achieve the required horizontal motion. Figure 6 below shows the slider mechanism and how the different components are connected together.

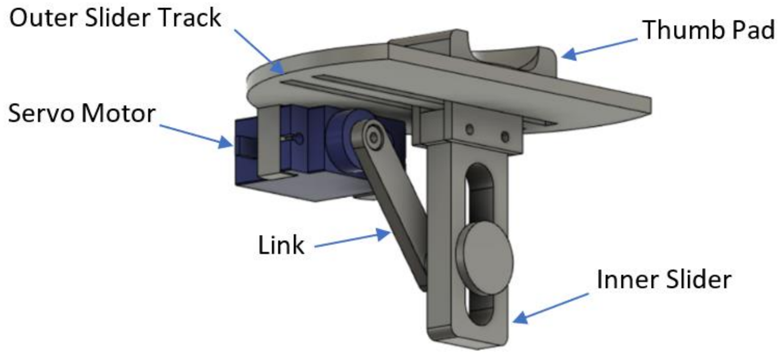
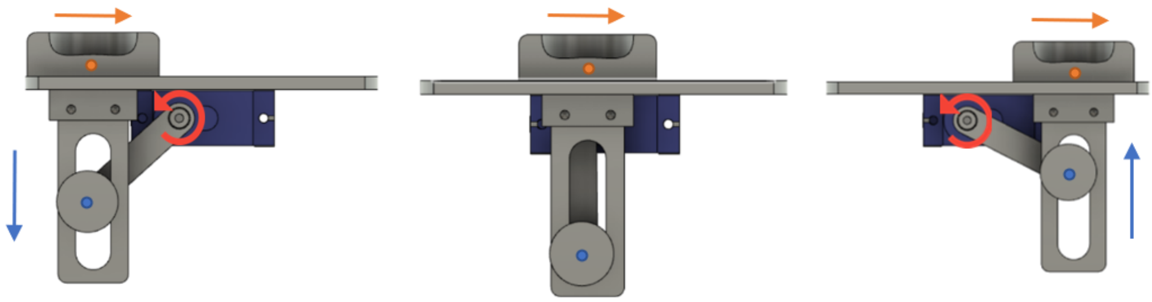


Fig. 6. CAD Model of the Second Slider Mechanism.

Figure 7 illustrates the front view of the slider mechanism motion sequence in different positions when the servo's shaft turns anticlockwise and the base, outer slider track, is fixed in place.



(c) Slider left position. (a) Slider middle position. (b) Slider right position.

Fig. 7. Second Slider Mechanism movement sequence.

This mechanism design was then 3D printed and tested before making the whole unit to check for any faults and misalignments, as well as checking the result print quality. After 3D printing the pieces and assembling the mechanism, it was found that some improvements can be done to improve the performance of this mechanism. One of the issues found was that the joint between the link and the shaft of the servo motor was loose, causing the link to slip when a relatively large resistance is present at the thumb pad. Additionally, the link between the servo and the inner slider was longer than needed and it could be made shorter while keeping the whole range of motion by allowing the servo to turn from 0° to 180° when needed.

As a result, a new shorter link that has an opening to house the servo horn was designed so that the servo horn can be screwed to the shaft using 2 mm screws. It also features a shoulder part to constrain the motion of the inner slider within its track, the mounting hole is off-centred to be able to use the edges of the shoulder as a screw washer as shown in Figure 8 below.

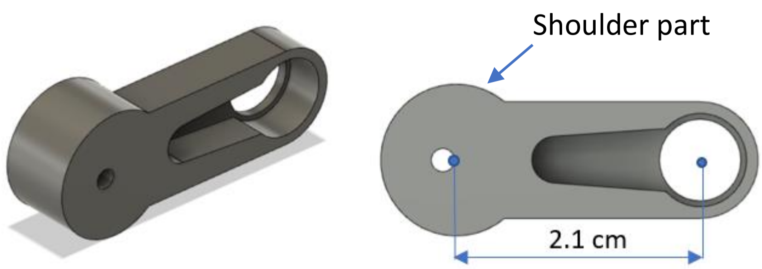


Fig. 8. Shorter Link with a Slot for the Servo Horn.

The second mechanism slider design was found to be more suitable for the feedback unit as it is more compact, takes less space inside the unit and the thumb pad slider path was straighter, making it easier to control without much friction with the slider track rails. Furthermore, a higher torque motor (HS-81 2.6 kg.cm) was used to ensure that the servo motor will not stall when applying higher resistance to the thumb pad.

After refining the design and making mounting holes, the unit housing was then designed to house the mechanism and the electronics, shown in Figure 10. The unit's handle was made to be angled by a 40° to make it more comfortable to grip, allowing the user's thumb to rest on the thumb pad in preparation for movement.

Figure 9 shows the final design of the slider mechanism with the mounting holes to mount it to the unit housing.

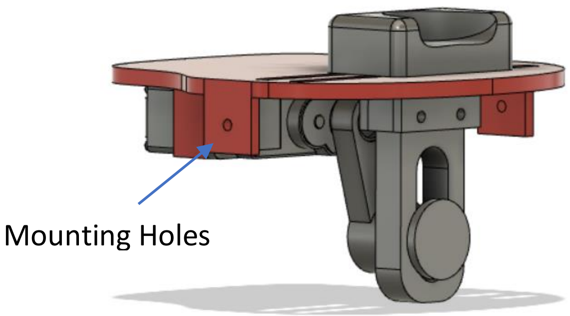


Fig. 9. Final Slider Mechanism Design.

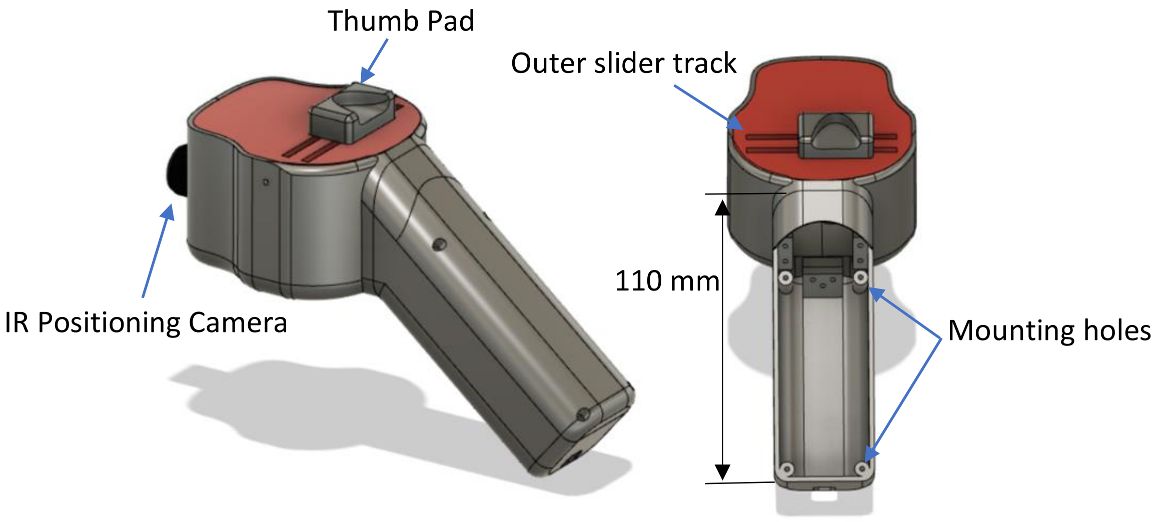


Fig. 10. Completed Haptic Feedback Unit.

3.3 IR Positioning Camera

An infrared positioning camera has been selected to be used in the feedback unit as it is able to detect the position and the distance from the robot dog with respect to an IR LED bar mounted on the back of the robot.

The Wii IR Camera meets the needed requirements making it a suitable choice to be used in the feedback unit. With its small form factor and high sensitivity, in addition to including a 128x96 monochrome camera with built-in image processing, it is capable of tracking up to four moving IR sources at a time [30]. This makes it an ideal choice for accurately detecting and following the movements of the robot dog.

The IR camera connects to Arduino Nano via the I2C protocol. The camera's built-in processor uses eight subpixel analyses to provide 1024x768 resolution for the IR-tracked points. The camera has an effective field of view of around 33° horizontally and 23° vertically.

Moreover, the camera features an IR-pass filter that comprises a dichroic-coated glass. This filter enhances the camera's ability to detect 940nm light sources, providing twice the intensity compared to 850nm sources [30].

When The IR camera detects the LED bar on the back of the robot dog. The microcontroller stores the data in data buffers and smooths it to reduce any noise or fluctuations in the signal. After that, it tracks the movement of the LED bar and maps these movements to the servo motor in the feedback unit which in turn controls the thumb pad to point in the direction of the robot.

3.3.1 IR Camera Initialisation

The IR camera has 3 main states: ON but not taking data, ON and taking data and half sensitivity and ON and taking data at complete sensitivity. The sensitivity mode in which the camera operates is controlled by two configuration blocks.

It is recommended by the manufacturer to set the sensitivity as high as possible, to achieve the highest sub-pixel resolution [30]. As the sensitivity decreases, the sub-pixel resolution also decreases, eventually approaching the sensor's actual resolution of 128 x 96.

3.3.2 Distance Measurements using IR Camera

Figure 11 illustrates how the IR camera detects the two light sources of the IR LED bar. The two IR LEDs are separated by a distance (L), and the IR Camera is a distance (d), from the IR LED bar. The light emitted by the LEDs is detected by the camera as two points separated by a distance (r). In order to calculate the distance (L) it is important to measure the angle, α shown in Figure 11 bellow.

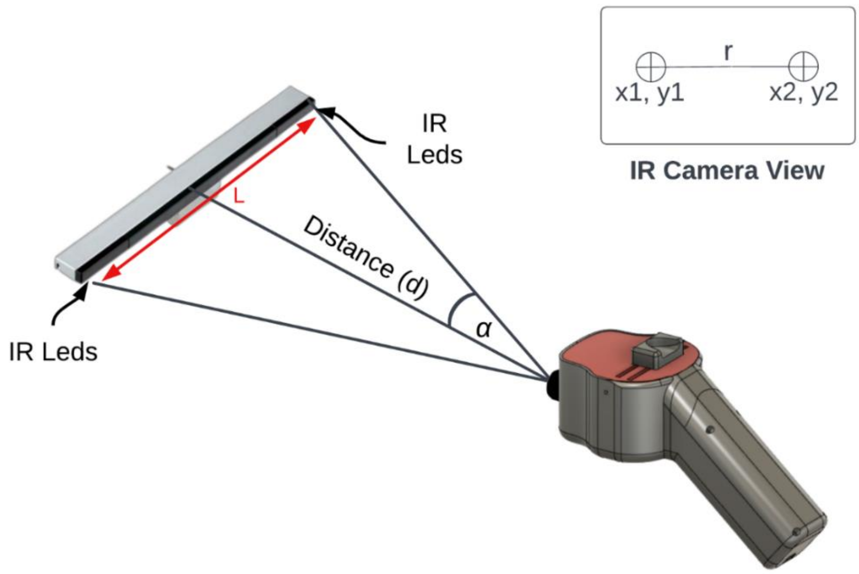


Fig. 11. Geometrical description of the feedback's IR camera tracking the IR LED bar.

The camera angular field of view per pixel (θ_{FOV}) can be determined from the given angular field of view of the camera in both the horizontal (HFOV = 33°) and vertical (VFOV = 23°) directions. As There are 1024 pixels in the horizontal direction and 768 pixels in the vertical direction, θ_{FOV} can be calculated as follows:

$$\theta_{FOV} = \frac{\left(\frac{HFOV}{1024}\right) + \left(\frac{VFOV}{768}\right)}{2} \quad (1)$$

The distance between the two dots on the camera view (r) can be calculated using their individual coordinates:

$$r = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \quad (2)$$

Therefore, the total subtended angle between the two sources and the IR camera is:

$$2\alpha = r.\ \theta_{FOV}, \qquad \therefore \alpha = \frac{r.\ \theta_{FOV}}{2} \quad (3)$$

Given the angle (α) and the known distance between the two light sources (L) of 200 mm, the distance between the IR camera and the IR bar can be calculated using trigonometry as follows:

$$d = \frac{L}{2\tan{(\alpha)}} \quad (4)$$

These equations were then implemented in the microcontroller code. The serial monitor showed the measured distance using the IR camera, which was then compared with the actual distance values measured using a measuring tape.

3.4 Vibration motors

Four vibration motors were implemented inside the feedback unit to provide tactile information to the user. The vibration motors transmit different vibration patterns to the index, middle, ring and little fingers to alert the user in different scenarios. The vibrion motors were placed on rubber mounts to isolate them and prevent the vibrations from spreading across the whole unit and affecting other fingers.

As Blind people can feel insecure in the absence of tactile feedback [18], the vibrations are retained as long as the robot is moving. The feedback unit receives the robot's moving direction and measures the distance from the user to the robot. If the distance is within the specified range, the vibrations will be continuous, but whenever the distance is longer or shorter than the specified range, the vibrations will become intermittent. Table 2 below shows the guiding vibration patterns when the robot dog moves.

Table 2. Vibration Patterns of the Feedback Unit.

Robot Moving Direction	Finger of Vibration	Distance from the robot	Vibration Pattern
Forward	Index Finger	With in the range	Continuous
		Longer than 2.5m (walk faster)	intermittent
	Little Finger	Shorter than 1m (slow down)	intermittent
Right	Middle Finger	-	Continuous
Left	Ring Finger	-	Continuous
Backward	Little Finger	-	Continuous
Stop	Little Finger	-	One Pulse

When the robot is moving forward and the distance between the user and the robot is within the specified range (0.6 -1.6 m), the Index vibration motor will vibrate continuously. However, if the user slows down or moves out of the specified range, the Index vibration motor will vibrate intermittently to indicate that the user is no longer in the optimal range.

If the user gets too close to the robot and the distance falls below 0.6 m, the little finger vibration motor will vibrate intermittently to signal that the user is too close to the robot. This approach of applying vibrations on a different finger when the distance from the robot gets shorter than the specified distance was found to be more suitable with the available vibration motors as varying the vibration frequency of a single vibration motor (on the Index finger for example) was difficult to distinguish when multiple motors are vibrating at the same time.

When the robot moves either right or left the vibration motors on the middle and ring finger will vibrate respectively. As the unit slider is pointing in the direction of the robot at all times, the vibration motors will only work went the robot is moving to help the user to navigate more effectively and intuitively.

3.5 Handling different scenarios

During the designing process of the feedback unit, careful consideration was given to the various potential scenarios that users might encounter while using the unit. One such scenario is when the IR camera loses sight of the IR LED bar mounted on the back of the robot guide dog. In this situation, the feedback unit will start a time counter and if it cannot detect the IR LED again within a certain duration (3 s), it alerts the user using a buzzer connected to the Arduino Nano. This approach of using a spirit buzzer to alert the user was chosen to keep the vibration patterns simple so that they can be easier for the user to learn.

Another potential scenario is if the robot dog stops moving due to some malfunction or other problem. In this case, the feedback unit will alert the user by making the vibration motor on the little finger vibrates one long pulse, indicating that the user should stop moving and take an appropriate action.

To ensure that the Haptic feedback unit remains functional, a battery-level monitoring circuit has been implemented. This simple circuit consists of a voltage divider connected to an analogue input pin of the Arduino. The user will be alert if the battery level is low by playing a different tone through the buzzer. This allows the user to recharge or replace the battery before it becomes completely depleted.

3.6 Electrical Design

A simple circuit was made to power the vibration motors using transistors instead of directly powering them from the Arduino Nano. This is because transistors can handle larger current loads than the output pins of the Arduino, providing greater power-handling capabilities. Furthermore, transistors offer protection to the Arduino from the back EMF generated by the motors, making the circuit more reliable [31].

Figure 12 below demonstrates the vibration motors' schematic diagram. The circuit consists of 4 DC vibration motors connected in series with 33 Ω resistors to limit the amount of current flowing through the motors. The motors are also connected in parallel with 0.1 μF capacitors to absorb voltage spikes produced when the motor brushes open and close [32].

The ULN2003A transistor array, on the other hand, is used to control the flow of current to the motors instead of powering them directly from the Arduino and hence allows for a larger current flow with less strain on the Arduino's components. The transistor array also has a built-in diode that protects the transistor from voltage spikes that occur when the motor is turned off. Additionally, the 1K ohm resistors protects the Arduino by preventing to much current from flowing through the Arduino output pins.

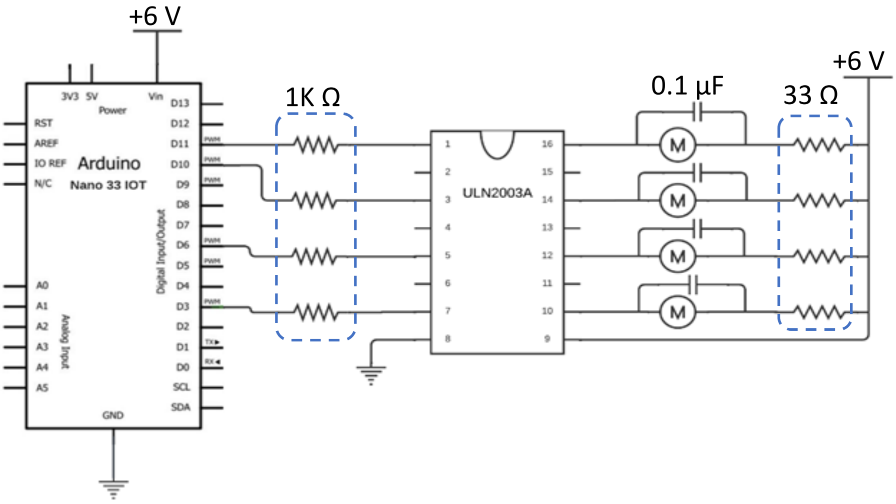


Fig. 12. Vibration Motor Circuit Schematic Diagram.

Figure 13 below shows the wiring diagram of all the electric components inside the haptic feedback unit including the vibration motors circuitry, the IR camera, buzzer and the servo motor.

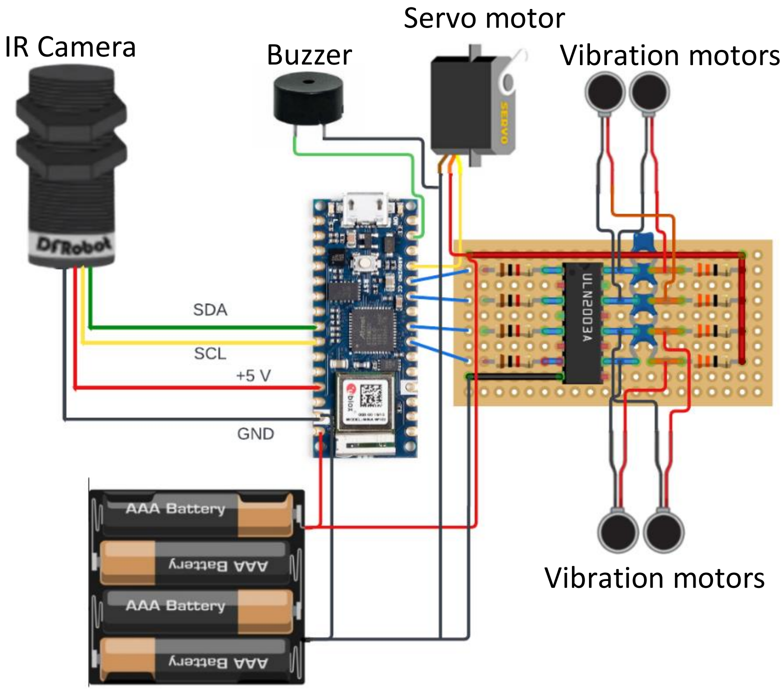


Fig. 13. Wiring Diagram of the Feedback Unit Components.

3.7 Robot Simulation

In order to check the functionality of the feedback unit, the robot was driven using a remote control and the directional data were obtained and sent to the feedback unit via Arduino Uno's built-in Bluetooth module. Before implementing the code on the real robot, a simulated environment was utilized to test multiple approaches for driving the robot. This allowed for code checking and experimentation to refine the robot's behaviour before deploying it on the actual hardware.

An open-source software framework for building robotics applications (ROS Melodic Morenia) running on a Debian Linux distribution-based operating system (Ubuntu 18.04.6) was used to run simulations of the robot using a 3D robot simulation environment (Gazebo Simulator).

Gazebo Simulator integrated into ROS Melodic software was used to provide a seamless interface between the simulation environment and the robot control firmware. This also allows for accessible communication between the simulator and the robot, providing a comprehensive simulation environment as well as improving the system's reliability [33]. The integrated simulation package (gazebo_ros_pkgs) is a set of ROS plugins and ROS-compatible libraries that connects the Gazebo simulator with the ROS framework, it provides the necessary interfaces to simulate the robot using a simplified message description language, also known as ROS messages, services and dynamic configurations [33]. A 3D visualization tool for ROS (RVIZ) is also used to visualize the movement of the robot before applying the physics engine on the robot in Gazebo [34].

The ROS simulation packages for Unitree robots (unitree_ros) was downloaded from the Unitree Robotics GitHub webpage, the package provides the Unified Robotic Description Formats (URDF) of all the unitree robots including the Unitree A1 intended robot. It also provides low-level control that allows controlling the torque, position, and angular velocity of the robot joints. The unitree_ros_to_real package offers low-level as well as high-level control to control the walking direction and speed of the robot, in addition to sending control commands to the real robot from ROS.

In order to control the robot motion using an external joystick controller as well as providing autonomous navigation to the robot, another package (CHAMP) was downloaded from Legged Robots Research GitHub webpage. The CHAMP control framework is based on "Hierarchical controller for highly dynamic locomotion utilizing pattern modulation and impedance control:

implementation on the MIT Cheetah robot" thesis [35]. It allows controlling the robot remotely via a teleoperation node using a simple controller (gamepad) in addition to fully autonomous navigation using ROS navigation Stack.

Firstly, a Catkin workspace was set up, and all the related dependencies such as (champ) and (champ_teleop) were installed. After that, the workspace was built to make the package ready to run, for more details check [36].

The URDF file of the Unitree A1 robot dog was provided to the CHAMP package and the walking demo was tested in RVIZ and controlled via the teleoperation node. The program first communicates with the joystick through the Linux joystick drivers and then publishes a (sensor_msgs/Joy) message which provides a list of which axes and buttons were pressed at that instance. This data is then sent to the (Teleop) node which converts it to a velocity command and passes it to the simulator to be visualized in RVIZ as shown in illustrated in Figure 14 below.

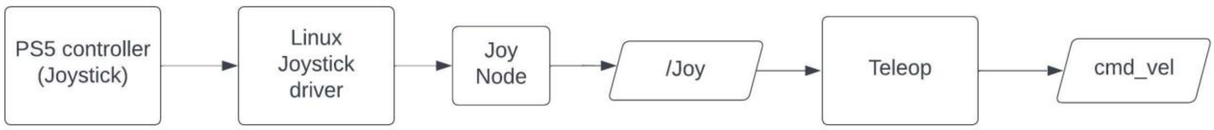


Fig. 14. Block diagram of the teleoperation communication between the joystick and the robot.

The robot was then spawned and run into the Gazebo environment where the default world was launched. Finally, the Teleop node was relaunched to perform teleoperation control on the robot.

3.8 Communication Between the Robot and Feedback Unit

Figure 15 below shows the structure of the Unitree A1 robot. An Arduino Uno Wifi Rev2 board was connected to the robot's internal non-real-time board via USB. The movement direction of the robot, directional data, is obtained from the Controller Board using a package located on the non-real-time board. These data are then sent to the Arduino Uno using a C++ serial library installed on the non-real-time board.

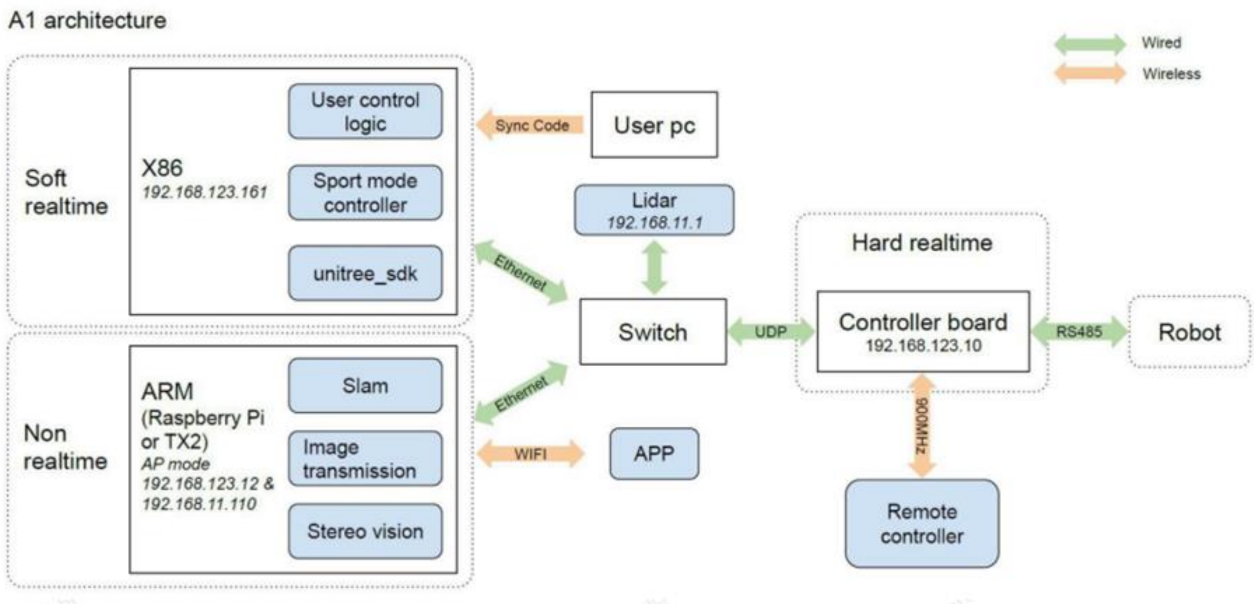


Fig. 15. Robot system schematic [36].

The operation system of the robot Onboard PC is a real-time Linux (Ubuntu), which has a maximum real-time communication bandwidth of 1000 Hz [37]. When the robot is operated using the remote controller, data is sent directly to the main controller board that controls the movement of the robot according to the received data. On the other hand, when the robot is controlled using ROS or the unitree_legged_sdk tool, the internal switch that connects the SPORT, real-time control board, and the perception control board to via ethernet passes the instructions to the main controller board.

3.8.1 Robot API

The user control of the robot offers two distinct modes: high-level and low-level control. The system permits the user to select only one of these modes at a time and does not allow for switching between them during operation. Under high-level control mode, the robot is treated as a control object that can be given instructions, such as the travel speed to control it without the need to build complex dynamic controllers. As the robot can be operated in normal mode and well as motion mode, it is important to initialize the UDP target IP and port based on the mode the robot will be using [36].

During the low-level mode, the robot's joints are controlled using three main loops for speed, position and torque. when operating in the low-level mode, it is necessary to switch the robot operation to normal saturation mode before running the routine. This routine is useful for testing; however, it will not be used to drive the robot in this situation as it requires joint locking

Testing the robot in simulation provided a better understanding of the robot internal software structure that allows the robot to operate wither using the provided remote controller, or via the unitree_legged_sdk tool available on the unitree robotics GitHub webpage. the unitree_legged_sdk tool is mainly used for communication between PC and the robot controller board, it also contains C++ example files that allows the user to perform low-level and low-level control.

3.8.2 Sending Data to the Feedback Unit

One of the unitree_legged_sdk C++ example files was used as a basis to communicate with the Arduino Uno board using the cross-platform serial communication library [39]. The C++ code communicates with the controller Board via high-level control using LCM Server explained in following subsection 3.8.3. After setting the connection, it stores the data sent to the robot while operating it using a remote control and determines the direction in which the robot is moving. Once the data is received by the Arduino Uno (mounted on the Robot), it sends the data to the Arduino Nano in the feedback unit using the NINA Bluetooth module available on the Arduino board. Based on the robot moving direction, certain vibration patterns be triggered to guide the user as presented in section 3.4.

3.8.3 LCM Server

The User Datagram Protocol (UDP) instructions are needed to be sent to and from the controller board, Ros 1 real-time performance is not guaranteed and is not suitable for real-time embedded systems applications [39]. ROS Subscribers and Publishers are not adapted to transfer data in communication with the robot. Therefore, LCM is used to transfer messages between internal processes. In LCM Server, LCM commands will be converted into UDP commands to send to the non-real-time board, whereas, UDP status will be converted into LCM status to send to the controller board. In ROS, a node can be set up to send LCM commands and receive LCM status in a separate manner.

4 Results and Discussion

Five main experiments were performed in order to test the designed feedback unit and characterise its performance. The first experiment focused on testing the IR camera tracking functionality to use its outputs to control the slider mechanism. The second experiment compared the distance measured using the IR camera to the actual distance measurements in order to find the associated error.

The third experiment tested the vibration motors functionality for the forward and backward motion of the robot. The control signals sent from the moving robot to the feedback unit were analysed with respect to the distance measurements.

The fourth experiment tested the left and right motion control signals with respect to the servo motor angle. Finally, the last experiment illustrates the behaviour of the feedback unit when the IR positioning camera loses sight of the robot dog.

4.1 IR Tracking and Servo Angle Mapping

The Arduino serial monitor was used to display the X-Y coordinates of the light sources detected by the IR camera. Upon testing, it was determined that the IR camera can detect both the IR light sources at the same time from a minimum distance of around 0.25 m and a maximum distance of 4 m. It was also found that the angle by which the feedback unit can tilt before it loses sight of at least one of the two IR light sources is around 30° in the horizontal and vertical directions.

In order to characterise the IR camera tracking performance when tracking the IR sources, the feedback unit was attached to a vertical string allowing it to swing like a pendulum with the IR LED bar directly below it. When the feedback unit was displaced from its equilibrium position, it oscillates in simple harmonic motion.

The Graph in Figure 16 shows the X coordinates of the detected IR light sources with respect to time when the feedback unit oscillates around the equilibrium position.

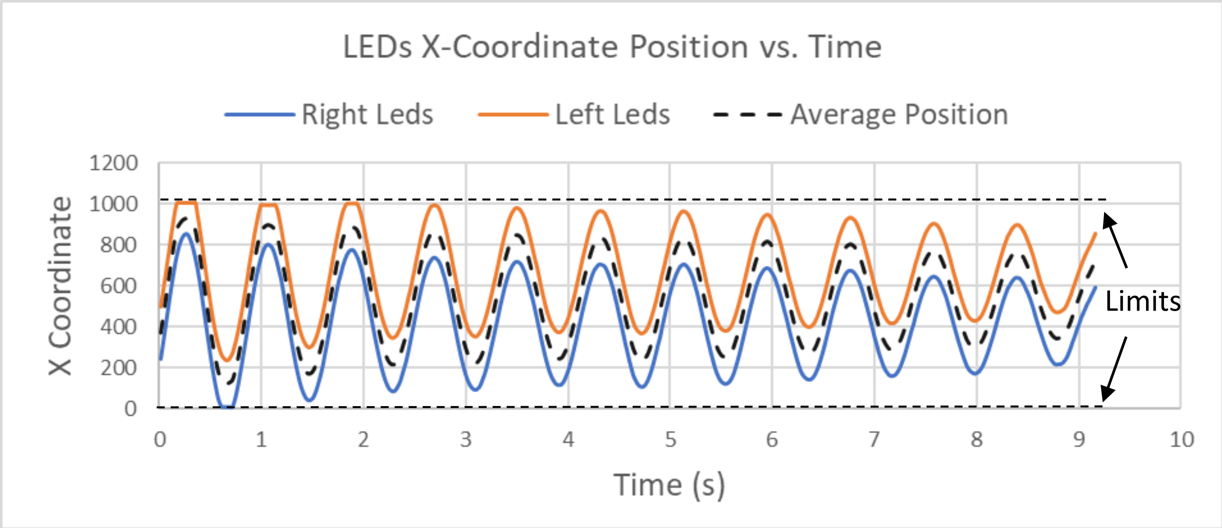


Fig. 16. LEDs X coordinates tracking results.

The graph presents the X-positions of the two IR light sources in addition to their average position calculated by the Microcontroller.

Since the Camera has 1024 pixels in the horizontal direction, the positioning of the IR light sources is mapped from 0 to 1023. As illustrated in Figure 16, it can be clearly seen that when the IR LEDs get out from the camera's field of view, the graph stays at either 0 or 1023 depending on the latest stored value for the detected LED position.

The calculated average position is then mapped to the servo motor’s angle to control the slider mechanism. Figure 17 below shows the servo motor’s angle corresponding to the LEDs average position when the feedback unit undergoes simple harmonic oscillations.

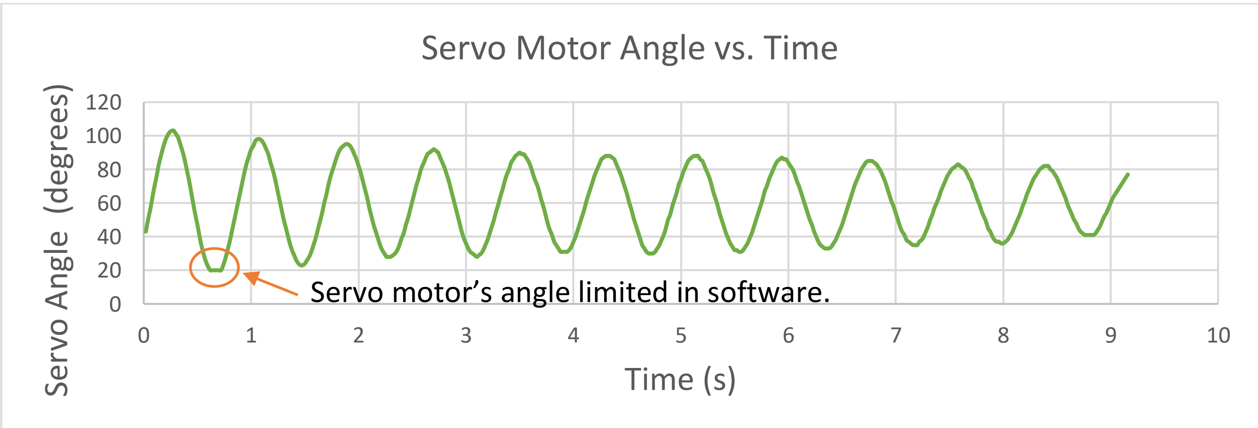


Fig. 17. Servo motor’s angle plot.

The mapped servo motor angle is limited by the code between 20° and 120°. This can be seen in Figure 17 where the servo angle cannot get lower than 20° as the average position reaches the specified limits.

The obtained results showed a high level of accuracy when tracking the IR LED bar from a distance of 1.2 m. The experiment was repeated in different indoor lighting conditions and the effect of the lighting on the readings was minimal. This is mostly due to the presence of the IR-pass filter on the camera lens. The camera's high accuracy will be beneficial when calculating the distance from the robot. It could also improve the guiding experience when navigating through narrow paths as it has a very fast response when tracking the LEDs position, making it a valuable tool for guiding visually impaired individuals in real-world scenarios.

4.1.1 Distance Measurements

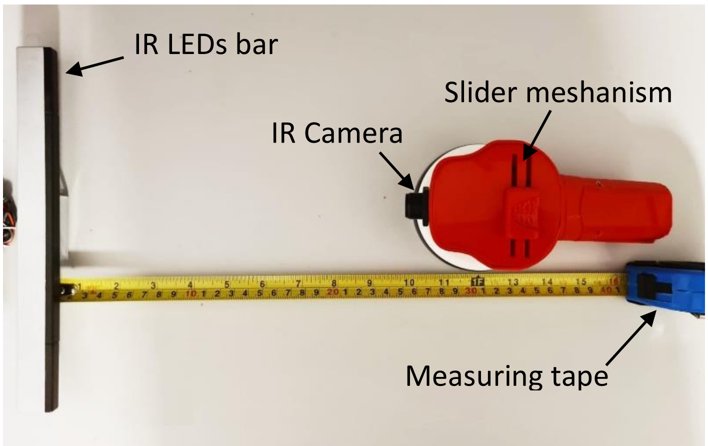


Fig. 18. Experimental setup.

Figure 18 illustrates the experimental setup of the feedback unit for measuring the distance from the IR LEDs bar.

The feedback unit calculates its distance from the robot using the X and Y coordinates as detailed in section 3.3.2. Figure 19 below illustrates the measured distance plotted against the actual distance measured using a standard measuring tape in order to calculate the resultant measurement error.

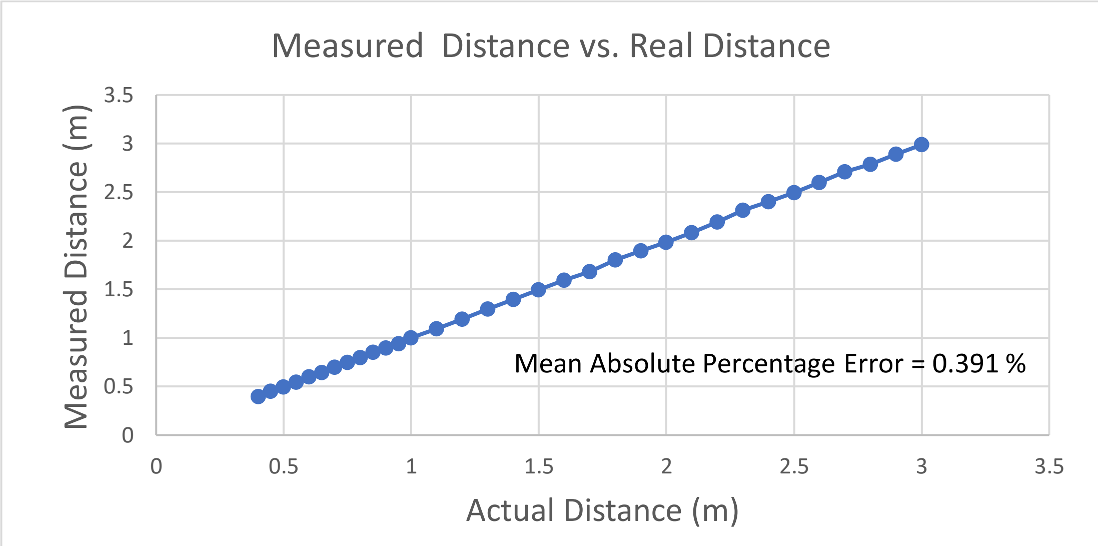


Fig. 19. Distance measurements plot.

The mean absolute error MAE of the measured distance was found to be 5.73 mm while the main absolute percentage error MAPE was calculated as 0.391%.

With relatively low error values, the graph exhibits a highly linear relationship. This implies that the IR camera distance measurements are consistently accurate, with minimal deviation from the true distance. This precision of the distance measurements is essential when providing guiding vibration cues based on the measured distance between the feedback unit and the robot dog.

4.2 Vibration Patterns for the Haptic Feedback unit

When the robot starts to move, it sends directional control signals to the Arduino Uno via USB. These control signals indicate the four directions in which the robot is moving and they are referred to as "Forward Signal", "Backward Signal", "Right Signal" and "Left Signal".

The control Signals are then transmitted to the Arduino Nano in the feedback unit to provide different guiding vibration patterns depending on the feedback unit's distance from the robot. The Arduino nano controls the four vibration motors, one for each finger except the thumb, via Control signals referred to as "Index Finger Signal", "Middle Finger Signal", "Ring Finger Signal" and "Little Finger Signal".

4.2.1 Vibration Patterns Forward and Backward Motion

Figure 20 below illustrates the measured distance between the feedback unit and the robot, the control signals sent from the robot to Arduino UNO as well as the control signals of the vibration motors on the Index finger and little finger.

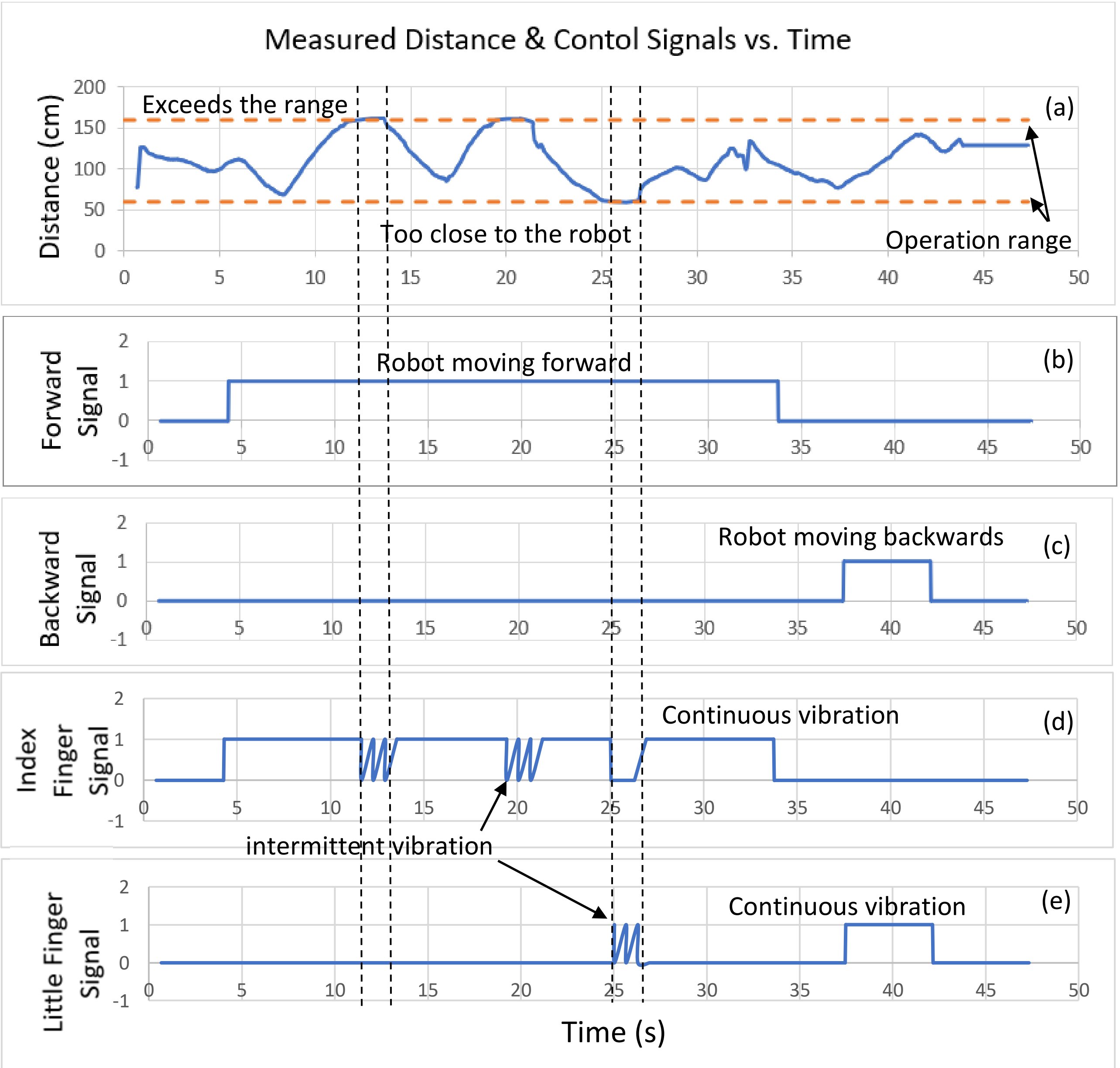


Fig. 20. Measured distance and control signals processed by the microcontroller.

Subplot (a) in Figure 20 shows the measured distance from the robot. When the robot starts moving forward, the control signal (Forward Signal) rises to one as shown in subplot (b). Following the vibration patterns in Table 2 (section 3.4), as long as the feedback unit's distance from the robot is within the specified operation range (60 to 160 cm), the vibration motors on the index finger will vibrate continuously as shown in subplot (d). However, when the distance from the robot exceeds 160 cm, the vibration pattern on the index finger will be intermittent with a time period of 600 ms (300 ms On, 300 ms Off).

On the other hand, if the robot is moving forward and the distance from the feedback unit becomes less than 60 cm, the control signal on the Index finger will stop (go to zero) while the control signal of the vibration motor on the little finger will vibrate intermittently (with a time period of 600 ms) as shown in subsection (d) and (e) respectively.

Finally, when the robot is moving backwards, the control signal (Backward Signal) rises to one as shown in subplot (c). As a result, the Little Finger Signal controlling the vibration motor on the little finger vibrates continuously to alert the user that the robot is moving backwards illustrated in subplot (e).

The total time delay between the initiation of robot movement and the vibration of the feedback unit was measured to be approximately 1.95 s. This delay comprises three main components. Firstly, the time required for the robot to transmit data serially to the Arduino Uno. Secondly, the time required for the Arduino Uno to transmit the data via the BLE Bluetooth module to the feedback unit. Finally, the processing time needed by the Arduino Nano to start the vibration motors.

The delay due to Bluetooth data transmission and Arduino processing is negligible when compared to the delay due to Serial Communication. The used serial library needs a delay of at least 400 ms in order to function correctly [37]. Once the directional control signals are received by the feedback unit, the Index Finger Signal and Little Finger Signal behave as expected following the directional control signals with respect to the distance operating range.

4.2.2 Vibration Patterns Left and Right motion

Figure 20 below describes the motion of the slider mechanism, represented by the angle of the servo motor over time, when the robot moves either right or left. It also presents the vibration motors' control signals for the middle and ring fingers.

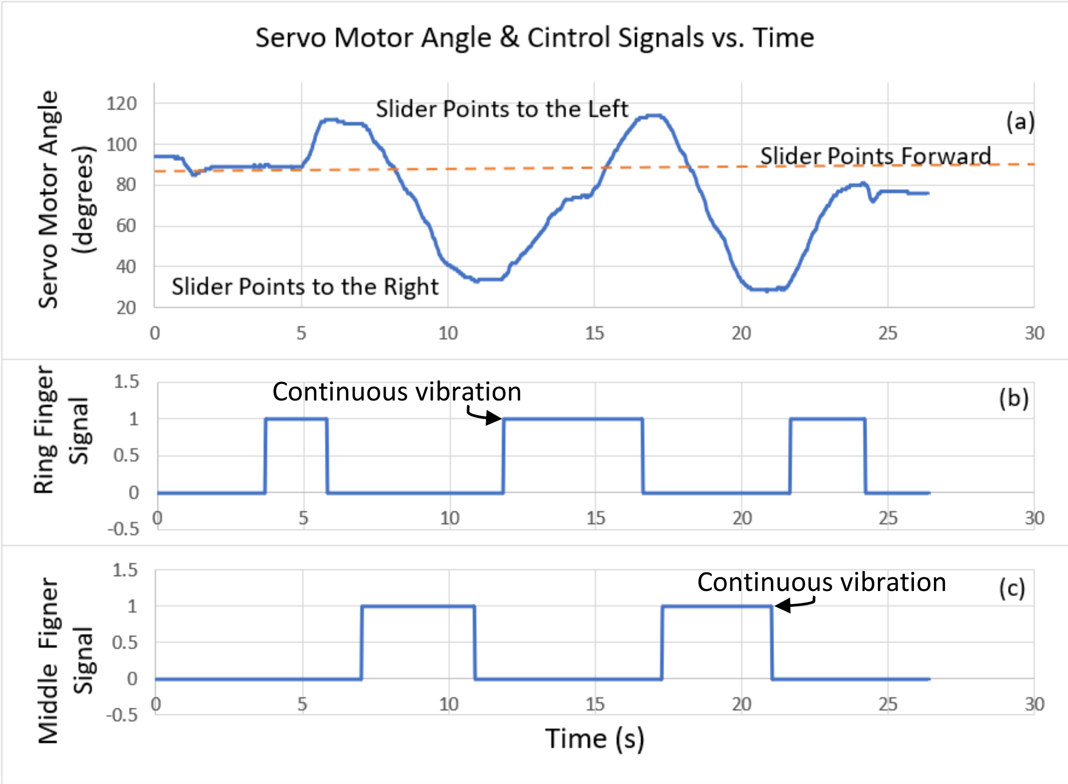


Fig. 21. Servo motor Angle and the corresponding control signals.

When the robot moves to the Left, the directional control signal (Left Signal) is sent to the feedback unit. On receiving the signal, the vibration motor on the ring finger goes to one causing the vibration motor to vibrate continuously as shown in Figure 21 subplot (b). Consequently, the slider mechanism points to the left indicating the position of the robot as shown in subplot (a).

On the contrary, when the robot moves to the right and the Right Finger Signal is received by the feedback unit, the Middle Finger Signal rises to one and its associated vibration motor vibrates continuously. At the same time, the slider mechanism points to the right as shown in subplots (c) and (a) respectively.

The slider points towards the robot at all times, however, when the robot starts changing its direction, the vibration motors, controlled by the Middle Finger Signal and Ring Finger Signal, are also turned on to reassure the user that the intended path is being followed.

4.2.1 Response on losing IR Signal.

When the feedback unit loses track of the IR LEDs mounted on the back of the dog, the Arduino Nano Starts a timer of 3 seconds. If the camera could not detect the IR LEDs within this time limit, it plays a tone to alert the user using a buzzer.

Figure 22 shows the IR signal of the detected LED source. As long as the IR camera can detect any of the two LEDs, the IR signal will equal one. Otherwise, the IR signal will fall to zero.

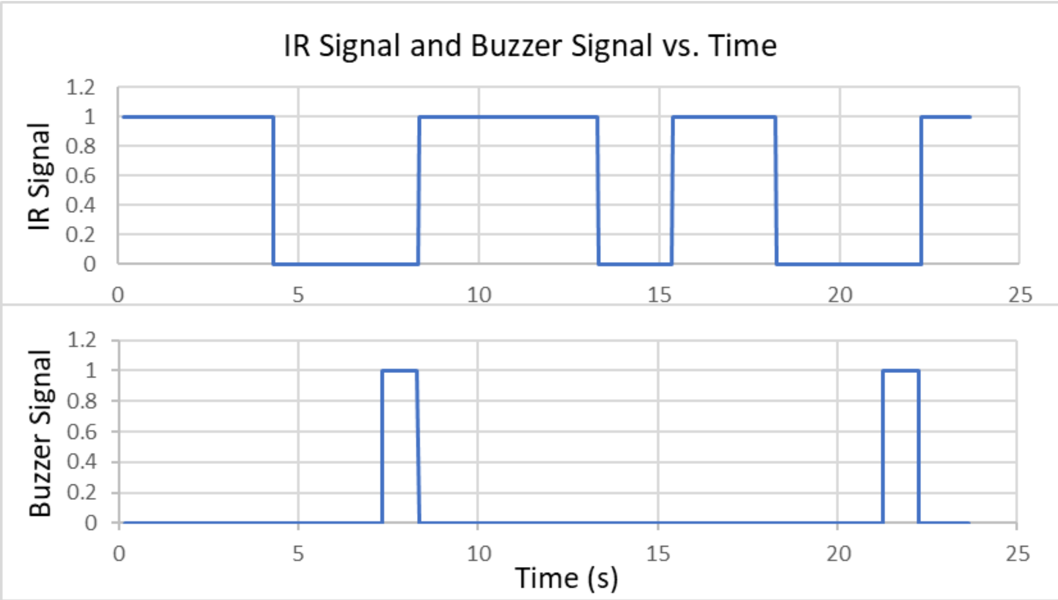


Fig. 22. IR signal and buzzer signal processed by the microcontroller.

It can be seen that the buzzer signal rises for 1 second to activate the buzzer when the IR signal is lost for 3 seconds or more. However, if the IR signal is lost for less than 3 seconds, the buzzer will not be activated.

This feature of being able to alert the user when losing the IR signal is crucial for guiding blind people as it resembles real-life scenarios, where some obstacles can get between the user and the guiding dog. Depending on the type of environment in which the feedback unit will be used and the user preferences, the timer counter can be changed to be shorter or longer.

After the buzzer turns on, the feedback unit can send a signal to stop the robot, however, it is not possible in this case as the robot is being controlled using its own remote controller to be driven around.

4.2.1 Summary

Overall, the functionalities of the haptic feedback unit work as expected. Starting from the accurate IR tracking in different indoor lighting conditions to mapping the tracking motion to the servo motor to control the slider mechanism. The slider mechanism itself provides the required horizontal motion, however, different designs can be considered to reduce its size making it more compact and allowing it to be fitted in smaller feedback units.

The unit can measure the distance with high accuracy when used within the specified range, thus, it can be used to provide reliable vibration patterns with respect to the distance measured from the robot.

The delay between the robot and the feedback unit can be reduced by investigating different C++ cross-platform serial communication libraries that support Linux to send data to the attached Arduino. Otherwise, a Bluetooth module can be connected directly to the robot's internal board so that data can be sent directly to the feedback unit after investigating the required configurations.

Finally, the feedback unit alerts the user when the IR LEDs signals are interrupted by playing a tone with a certain frequency (1 kHz in this case), and the frequency can also be changed depending on the user's preferences. Any Conditions or disabilities that the user might have should also be taken into consideration when using such alerting devices. For instance, if the user is deaf or cannot focus on auditory signals, different patterns and tactile inputs can be used to alert the user.

5 Conclusions and future work

5.1 Conclusions

In conclusion, designing a feedback unit is essential for improving the communication between the guiding robot and the user, where the unit is responsible for converting the directional data obtained by the robot into reliable and simple inputs for the user to follow.

Different haptic feedback unit designs have been investigated and compared to come up with a suitable mechanism to provide the required specifications. The designed feedback unit was tested to verify all the required basic functionality and all the haptic cues were intuitive to learn.

Further testing for the unit involving more participants should be carried out in order to validate the unit's performance in real-life scenarios.

5.2 Future work

Due to the presence of some limitations in the unit's design and the human-robot interaction, the system is subjected to future enhancement as follows:

- A faster cross-platform serial communication library should be further researched to enhance the feedback unit’s time response.

- Improving a tracking system by using sensors with a wider field of view, such as 360 cameras, gives the user a less restrictive holding pose of the feedback unit (more than 30°).
- Implementing the unit with a fully autonomous mobile robot for further testing.

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Appendices

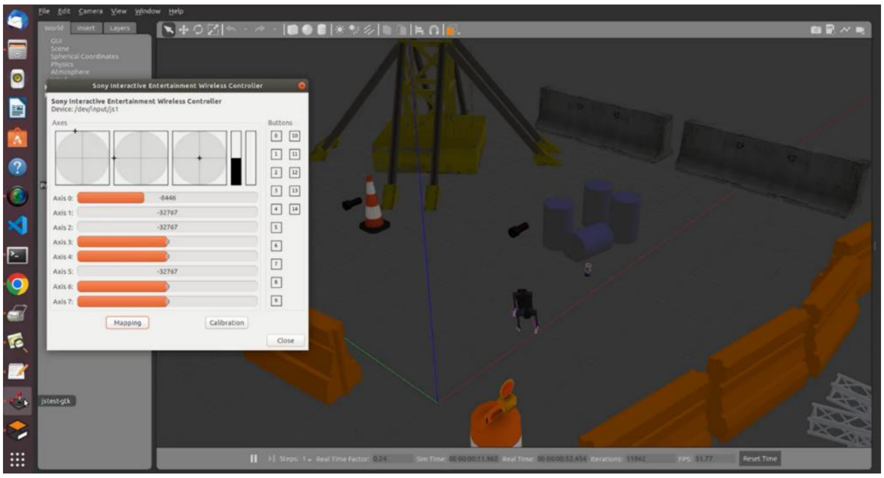

Fig. 23. Controlling the robot using a PS5 controller in simulation.

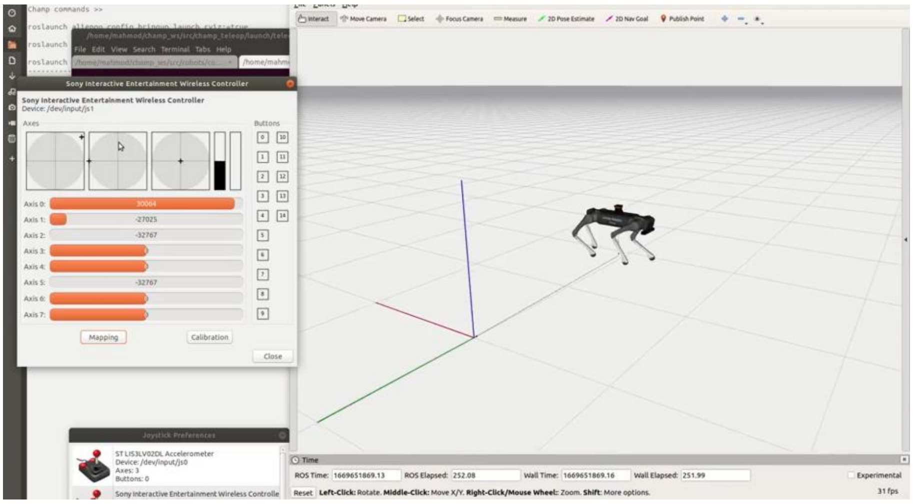

Fig. 24. Controlling the robot in RVIZ using a PS5 controller.

Link to the project GitHub Repository contains the code and CAD models of the feedback unit:

https://github.com/MahmodElShal/Indiviual-project

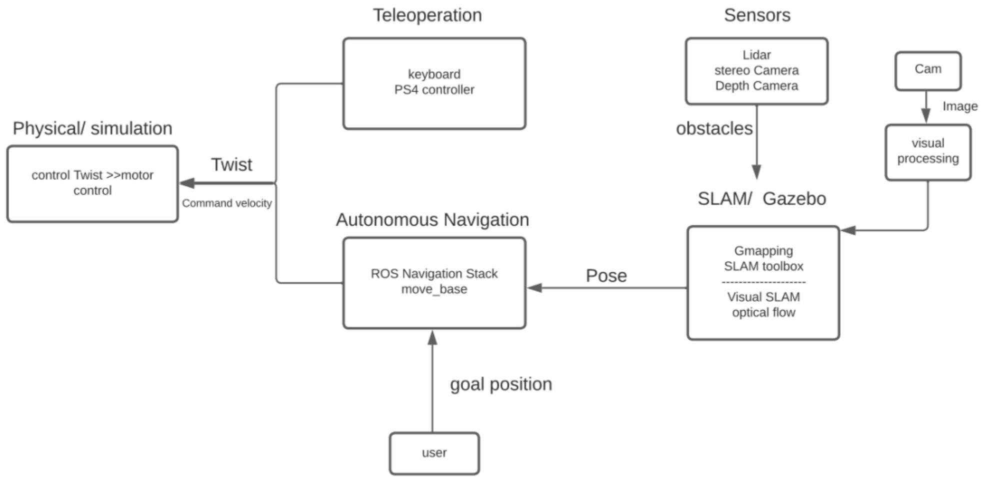

Fig. 25. Block diagram of the robot dog navigation system.

B Risk assessment

MANCHESTER 1824
The University of Manchester

General Risk Assessment Form

Date: 13/10/2022	Assessed by: Dr Simon Watson	Checked / Validated* by: Dr Simon Watson	Location: MECD	Assessment ref no (5)	Review date: (6)
Task / premises: GENERIC ACTIVITY RISK ASSESSMENT FOR ELECTRICAL WORK IN THE LABS. Building an Assistant Robot guide dog project involving the use of typical laboratory hardware, including soldering, the establishment of electric wire connections, Test and measurement, and using hand tools and equipment with mechanical hazards. As well as spending many hours coding on the computer.					

Activity (8)	Hazard (9)	Who might be harmed and how (10)	Existing measures to control risk (11)	Risk rating (12)	Result (13)
Use of equipment	Electricity	User and others in the area Can cause fire, burns or electric shock	1. User is trained and supervised until fully competent. 2. Visual inspection of equipment for obvious defects 3. Defective plugs, cables equipment etc reported for repair/replacement and taken out of use. 4. Check for PAT sticker is valid 5. Use equipment as per manufactures guide. 6. Sufficient power sockets provided to reduce need for extension cables. 7. Make sure wires and cables never make contact with liquid. 8. If faulty stop use immediately and report it to a lab technician. 9. Switch off and make safe after use.	Med	A

Result : T = trivial, A = adequately controlled, N = not adequately controlled, action required, U = unknown risk

University risk assessment form and guidance notes.
Revised Aug07

Activity (8)	Hazard (9)	Who might be harmed and how (10)	Existing measures to control risk (11)	Risk rating (12)	Result (13)
Regular computer use	Poor posture, repetitive movements, long periods looking at DSE (display screen equipment)	Staff, students, visitors Back strain (due to poor posture). Repetitive Strain Injury (RSI) to upper limbs. Eye strain.	1. Please refer to the DSE policy, guidance and poster for more information on how to set up your workstation properly 2. Complete DSE self-assessment for guidance on how to set up workstation properly 3. Set up workstation to a comfortable position with good lighting and natural light where possible 4. Take regular breaks away from the screen, at least some activity at your workstation every 20mins and a 5 minute break from workstation every hour. 5. Regularly stretch your arms, back, neck, wrists and hands to avoid repetitive strain injuries. Refer to workstation exercises here 6. Set up a desktop working space where possible and try to avoid working on a laptop without a docking station	Low	A
Use of hand tools (like sharp / pointed tools, Scalpel blade)	Sharp cutting edges	Users /Others in proximity / Visitors Risk of cuts and puncture injuries	1. User is trained and supervised until fully competent. 2. Only use the tool for the intended use. 3. Pre-use check for any faults and remove from use if any found. 4. Avoid use of 'open bladed' tools, e.g. use scissors instead of scalpels if possible. 5. Make safe after each use, e.g. razor blades to be put in sharps bin after use, knives to be replaced into protective cover. 6. Place in safe storage immediately after each use. Never leave cutting tools unattended. 7. Do not place cutting tools too close to the edge of workstation to avoid falling off onto legs and feet 8. Consider the use of cut resistant gloves 9. Use safe cutting technique e.g. cut away from the body and away from the hands and fingers	Med	A

Result : T = trivial, A = adequately controlled, N = not adequately controlled, action required, U = unknown risk

Activity (8)	Hazard (9)	Who might be harmed and how (10)	Existing measures to control risk (11)	Risk rating (12)	Result (13)
Use of equipment with mechanical hazards	User wearing loose clothing or long hair	User /Others in proximity / Visitors Risk of entanglement	1. Training and supervision on the machinery until fully competent. 2. Avoid loose clothing and loose jewellery. 3. Long hair must be tied back. 4. Users must wear lab coat, safety glasses BS EN 166 and cut resistant gloves BS EN 388. 5. A conveniently positioned mushroom shaped emergency stop button or is present to quickly stop the machine in an emergency. 6. Machinery turned off when not in use. 7.	Med	A
Moving /lifting large/heavy items (including furniture, PCs, stationary)	Moving heavy, large or cumbersome loads/object	Staff, students, visitors, cleaners Crush injuries, strains and sprains, bruising	1. Contact Technical Services Manager or University porterage for moves of large and or heavy furniture. Do not attempt lifting heavy items unless trained and experienced 2. For lighter items (generally below 10kg although dependant on individual capabilities), perform kinetic lifting with feet apart, load held close to body and in front of operator. 3. Perform good loading technique: check weight, centre of gravity, sharp edges, use stable position, bend knees not back, have a firm grip on load, keep load close to body, avoid twisting or stretching, avoid lifts above shoulders / below knees, move smoothly, avoid jerky movements 4. Do not store large, heavy or cumbersome items at height (eg on high shelves or on top of cabinets/bookcases etc).	Med	A

Result : T = trivial, A = adequately controlled, N = not adequately controlled, action required, U = unknown risk

Activity (8)	Hazard (9)	Who might be harmed and how (10)	Existing measures to control risk (11)	Risk rating (12)	Result (13)
Manual soldering Creation of joints between wires or components using molten solder. The application requires the use of a hot (~370-420oC iron) usually mains powered.	Heat	User / Visitors / Occupants of neighbouring areas Minor burns to skin, fire	1. No soldering equipment should be left unattended while switched on and for a minute after switching off to allow to cool. 2. Anyone approaching soldering equipment should assume it is hot. 3. 0.11mm nitrile gloves can be worn to protect hands from spitting solder 4. Solder away from combustible and flammable material 5. When not in use, soldering irons must be stored in the stands provided. 6. Cold water or burn gel should be applied immediately to all soldering iron burns and first aider called to assist.	Low	A
	Colophony (e.g. rosin) based solders that cause asthma All other solders	All users in lab Risk of asthma from Colophony Risk of irritant to respiratory system	1. The use of rosin-based solders and fluxes should be limited and require registration with occupational health by emailing the lab screen questionnaire to millocchealth@manchester.ac.uk (ask the Safety Advisor for a copy) 2. The use of local fume extraction is required when using rosin-based fluxes; or when using alternative fluxes for more than a few minutes a day, according to HSE guidance 3. If using extraction, do not begin task unless you have confirmed that the equipment is working. Ensure Allianz inspection is up to date and that the extraction is used as close to the fume source as possible 4. Label bottles clearly and decontaminate work area regularly 5. Keep away from food and drink areas and wash hand before leaving the lab 6. Add solders and fluxes to labcup	Med	A

Result : T = trivial, A = adequately controlled, N = not adequately controlled, action required, U = unknown risk

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Activity (8)	Hazard (9)	Who might be harmed and how (10)	Existing measures to control risk (11)	Risk rating (12)	Result (13)
	Solder pastes and fluxes	All users in lab Risk of allergic contact dermatitis	1. The use of solders and fluxes that cause allergic contact dermatitis should be limited and require registration with occupational health by emailing the lab screen questionnaire to millocchealth@manchester.ac.uk (ask the Safety Advisor for a copy) 2. 0.11mm nitrile gloves should be worn to protect skin from contact 3. Label bottles clearly and decontaminate work area regularly 4. Keep away from food and drink areas and wash hand before leaving the lab 7. Add solders and fluxes to labcup	Med	A
	Lead based solder	All users in lab Lead poisoning, increased risk for pregnant / breastfeeding mothers.	1. Lead at work guidance states below 500oC the lead fume is controlled, soldering irons do not reach this temperature (max 420oC) 2. Keep away from food and drink areas and wash hands after use 3. Add solders and fluxes to labcup	Med	A
Test and measurement	Electrical	Users /Others in proximity / Visitors Electric shock	1. User is trained and supervised until fully competent 2. Specific risk assessment required for: a. >50 volts AC / >60 volts DC b. intentional connection to human tissue c. low impedance situation, e.g. wet conditions		

Result : T = trivial, A = adequately controlled, N = not adequately controlled, action required, U = unknown risk

University risk assessment form and guidance notes.
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Activity (8)	Hazard (9)	Who might be harmed and how (10)	Existing measures to control risk (11)	Risk rating (12)	Result (13)
	Heat	User / Others in proximity / Visitors Minor burns, fire	1. User is trained and supervised until fully competent 2. Keep area tidy and free from combustible or flammable materials 3. Exercise caution on first power-up. Limit supply current to just above expected level. 4. Specific risk assessment required for circuits containing intentional heating elements and/or operating at >85oC 5. Consider signage to warn others of heat hazard above 85oC	Low	A
	Component ejection	User / Others in proximity / Visitors Minor burns, eye injury	1. User is trained and supervised until fully competent 2. Wear safety glasses 3. Exercise caution on first power-up. Check for reverse connection of electrolytic capacitors before energising the circuit. 4. Limit supply current to just above the expected level 5. Avoid close visual inspection of an unproven circuit during the first few minutes of operation	Low	A
General working in the teaching laboratory	Slips, Trips and falls	Staff, students Strains and impact injuries	1. Floors and walkways kept clear of items, e.g. boxes, packaging, equipment etc 2. Furniture is arranged such that movement of people and equipment are not restricted. 3. No running in the spaces 4. Drawers and cabinets kept closed. 5. Walkways to be kept clear of trailing cables, bags to be stored under desk or in the lockers provided. 6. Ensure floor remains dry and mop up any spilt liquids. 7. Reasonable standards of housekeeping maintained. 8. Report damaged flooring to Academic supervisor who will report appropriately 9. Adequate lighting provided. 10. At least one member of staff to be present at all times during timetabled laboratory sessions	Low	A

Result : T = trivial, A = adequately controlled, N = not adequately controlled, action required, U = unknown risk

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Fig. 26. Project Risk Assessment