EG2310

HARDWARE DESIGN DOCUMENTATION

GROUP 04

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1. INTRODUCTION

1.1 Introduction

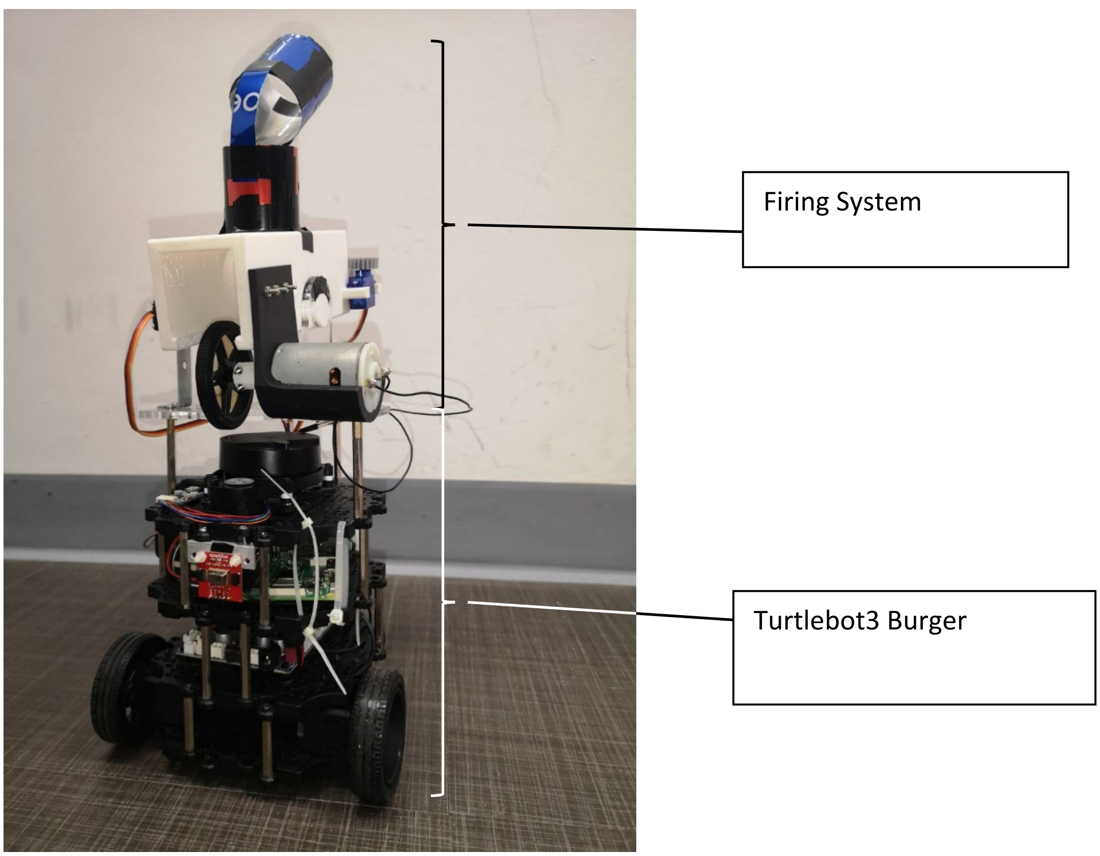
This document provides the details of hardware solutions implemented in response to the objective given in the EG2310 module. This document also provides details on how to operate the system.

1.2 Objective

The task given is to design and build a system to autonomously navigate and produce a SLAM map of an unknown area no larger than 8mx8m. While navigating, it must autonomously identify, aim, and fire a ping-pong ball projectile at a single target emitting an infrared signature no further than 2m.

1.3 System Overview

The system consists of a stock TurtleBot3 Burger with minor attachments and a firing system mounted above the TurtleBot. The system is designed to complete all the objectives in a 30-minute operating window.



1.4 Safety Warnings

1) Do not touch the firing mechanism when the robot is activated
2) The assembly contains small parts, keep it away from children
3) Keep the robot away from heat or fire
4) Keep the robot away from water or other liquid
5) Keep the robot away from edges to avoid it falling from heights
6) Stop using or charging the battery immediately if the battery becomes or appears damaged, gives off an odor, becomes discolored or deformed, starts to swell, leaks, exceeds a temperature of 160°F (71°C), or if anything else abnormal occurs.
7) Never disassemble, modify, puncture, mechanically shock, crash and/or short circuit the battery. Leakage, smoke emission, ignition, explosion, or fire, which may result in personal injury and property damage, can occur.
8) Never remove the battery from its protective plastic case.
9) Never discharge your Li-Po battery below the 3.2V.
10) Disconnect the Li-Po battery from the robot when not in use.
11) The Li-Po battery is not waterproof, keep it away from water.
12) Do not place the Li-Po battery in the microwave.
13) Do not store the Li-Po battery for a long time with battery capacity of over 50%.
14) Do not charge the Li-Po battery overnight or unattended.
15) Do not charge the Li-Po battery when connected to the TurtleBot.

2. OVERVIEW OF HARDWARE ARCHITECTURE

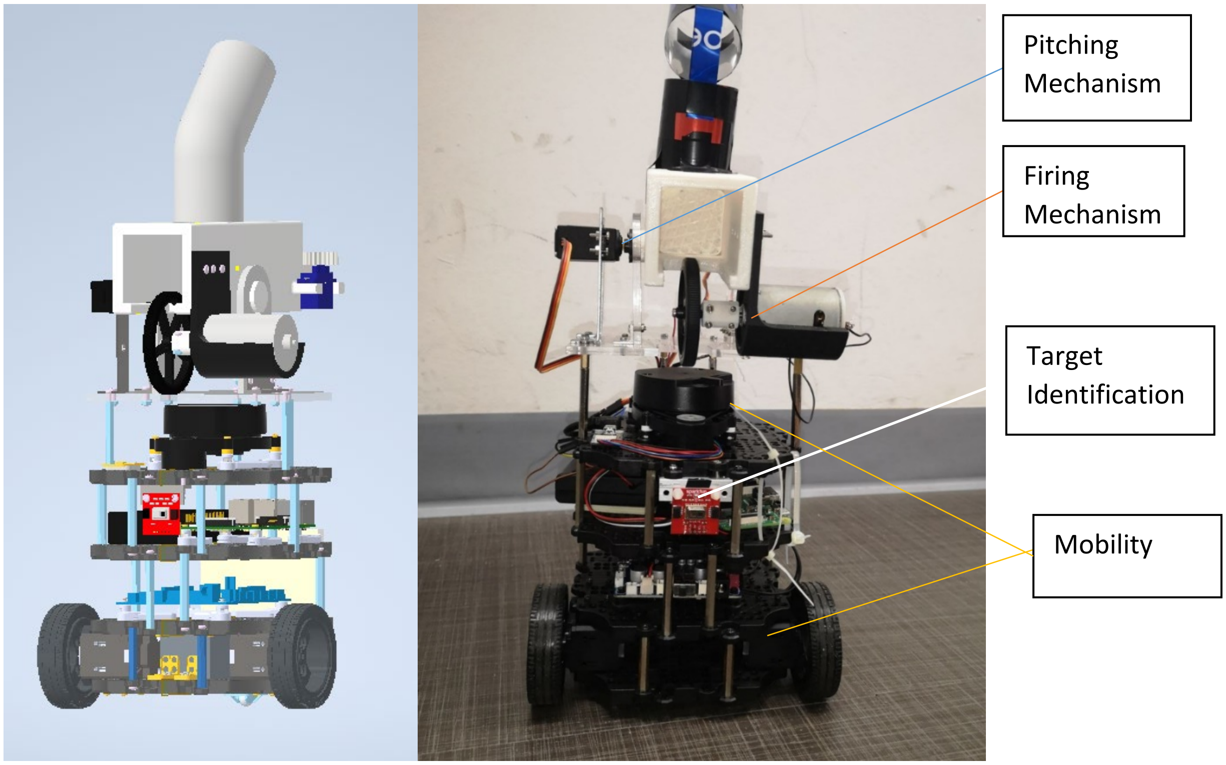


Figure 1: Overview of the product

2.1 Mobility

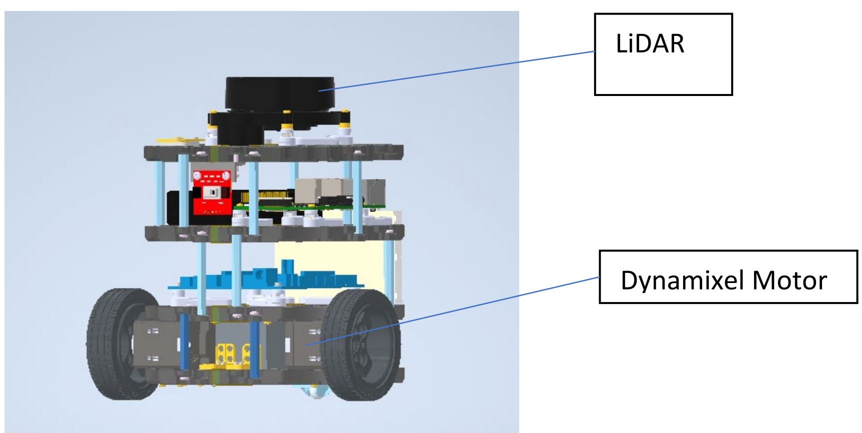


Figure 2: Mobility System

A TurtleBot3 Burger is used to move around. A LiDAR (model: LDS-01) on the robot is used to detect proximity of the surroundings for Navigation and Mapping. For more information, please refer to the Turtlebot3 e-manual at https://emanual.robotis.com/docs/en/platform/turtlebot3/appendix_lds_01/.

2.2 Target identification

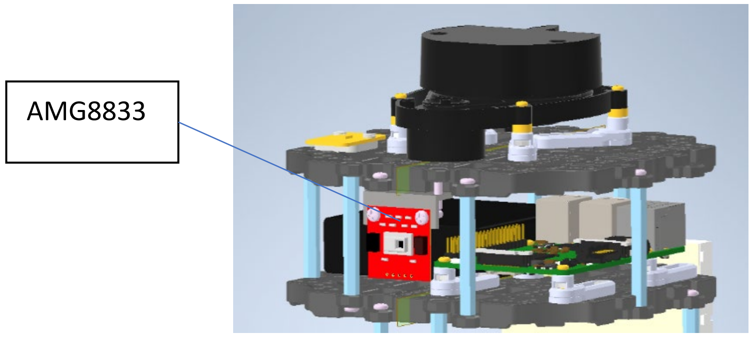


Figure 3: Target Identification

A thermal sensor, AMG8833, is used to detect the infrared signature of the target. The sensor returns an array of 64 values of thermal intensity which is analysed to orientate the robot to face the target head-on.

2.3 Pitching mechanism

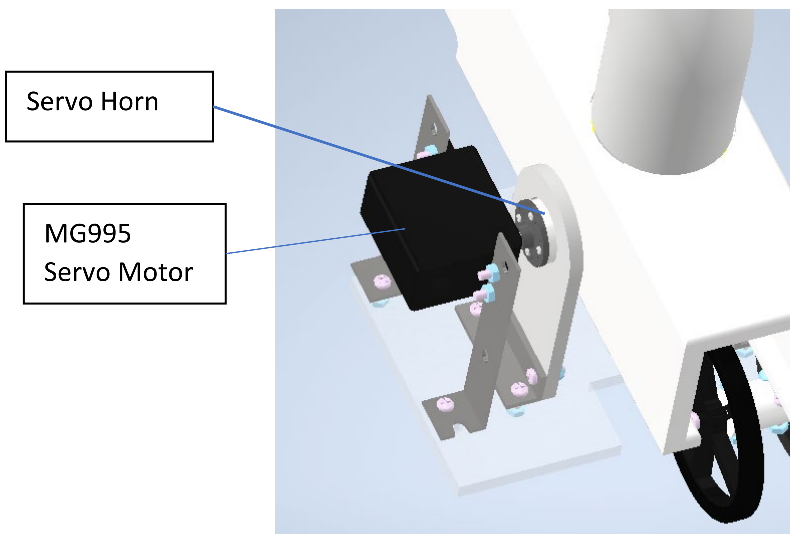


Figure 4: Pitching Mechanism

A non-continuous servo motor, MG995, is used to pitch the barrel to the desired angle. This servo provides precise angle control and sufficient torque for pitching. A servo horn is screwed onto the right side of the barrel on its circular extrusion. The pitching servo is fitted into the horn.

2.4 Ball feeding mechanism

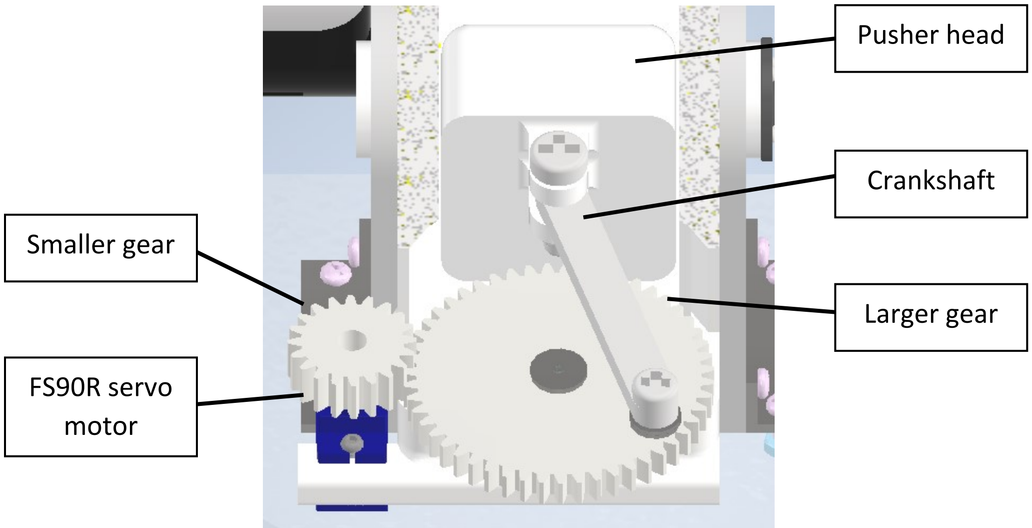


Figure 5: Ball-feeding Mechanism

The balls are fed to the flywheel using a custom crankshaft system. The parts for the crankshaft were 3D printed to fit custom dimensions. The crankshaft movement is driven by a gear system, where the larger gear is attached to the crankshaft and a smaller gear. The smaller gear is attached to a servo motor which would drive the motion of this system. When the crankshaft is at its extended position to push a ball, at the same time it blocks the other balls in the reloading barrel from dropping into the barrel. This system feeds the balls one at a time to the flywheel.

2.5 Firing mechanism

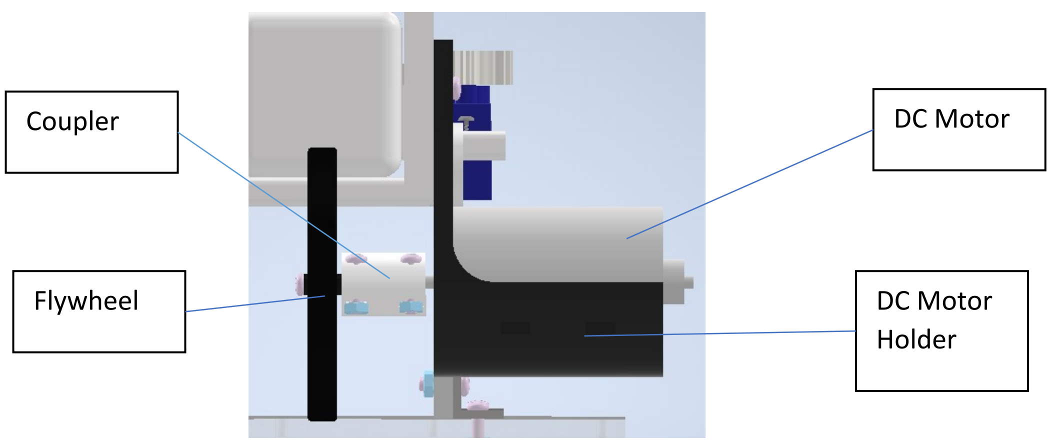


Figure 6: Firing Mechanism

The firing mechanism is a flywheel shooting mechanism. This mechanism involves a wheel accelerated to a high RPM by a DC motor. Ping-pong balls are then fed to the wheel through a barrel. The DC motor used is an RS DC Motor. The DC motor and flywheel are held by a motor holder screwed on the side of the barrel.

2.6 Process Flow Chart

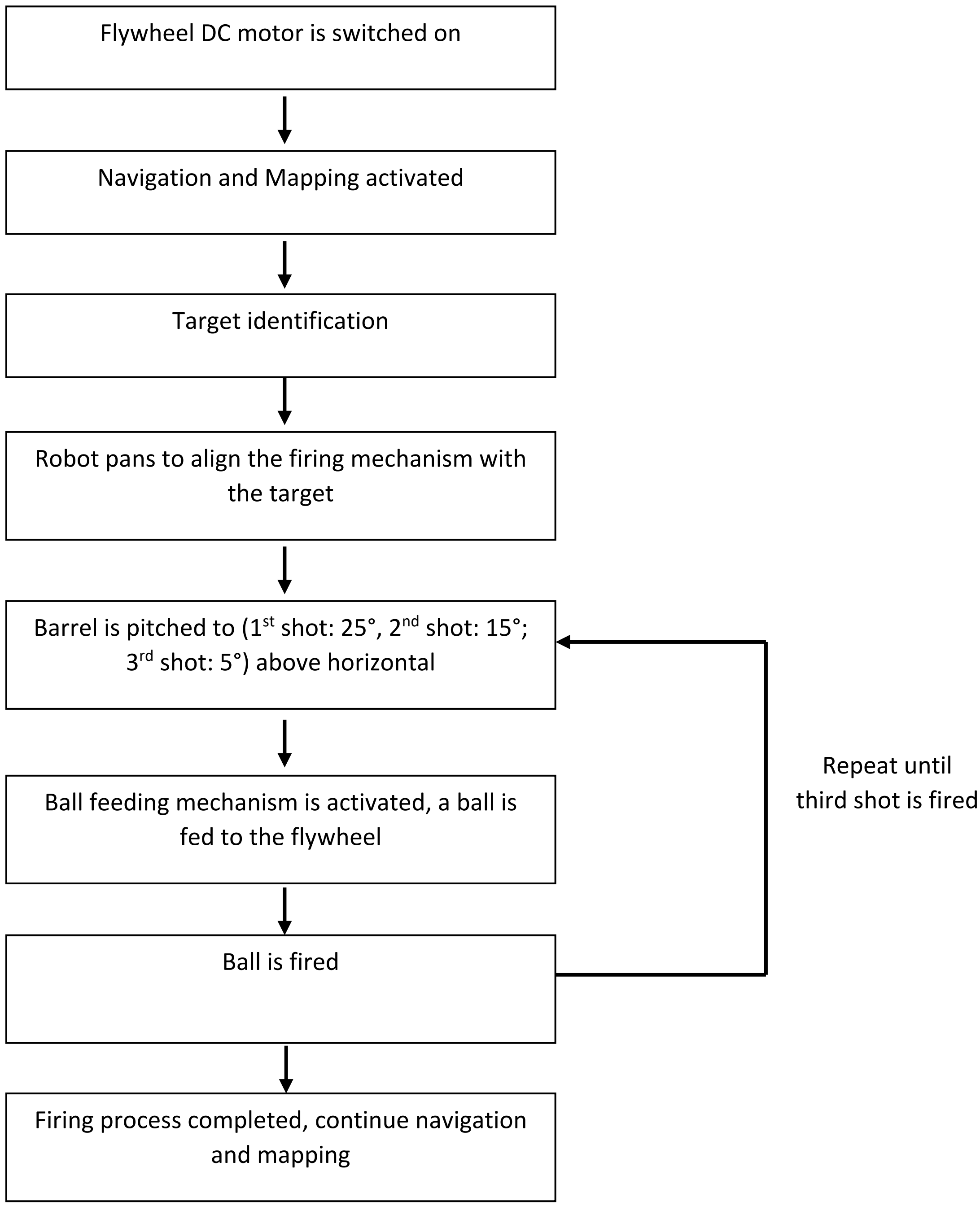


Figure 7: Process Flow Chart

3. ASSEMBLY

Steps:

1) Download the Assembly Manual for Turtlebot3 Burger from https://emanual.robotis.com/docs/en/platform/turtlebot3/hardware_setup/
2) Assemble the TurtleBot according to instructions in the Assembly Manual with the following changes.
    a. Place the USB2LDS on the top layer of the TurtleBot instead of the third layer.
    b. Fit the battery holder along with the Raspberry Pi on the third layer
3) Attach additional supports on the top layer of the TurtleBot.
4) Assemble the crankshaft system and insert it into the firing barrel. Screw the servo motor horn onto the circular extrusion on the right side of the firing barrel.
5) Insert the larger gear on the circular extrusion at the rear of the firing barrel. Screw to secure the small metal plate onto the circular extrusion. Ensure that the gear is able to rotate smoothly.
6) Connect the crankshaft system to the larger gear.
7) Attach the smaller gear onto the top of the FS90R servo motor. Align the smaller gear with the bigger gear, screw the servo motor onto the extrusion at the rear of the firing barrel.
8) Attach the DC motor onto the DC motor holder.
9) Connect the wheel to the DC motor shaft using a coupler.
10) Attach the DC motor holder onto the firing barrel.
11) Attach the left and right barrel supports on the acrylic base plate, with the firing barrel in between the supports. Secure the supports with metal brackets.
12) Attach the MG995 servo motor to the horn, ensure that the longer end is towards the front of the firing barrel.
13) Fasten both sides of the MG995 servo motor to the servo motor holders.
14) Attach the servo motor holders onto the acrylic base plate.
15) Attach the reloading barrel onto the hole at the top of the firing barrel.
16) Assemble the firing system on top of the TurtleBot by aligning the hole on the base acrylic plate of the firing system to the supports.
17) Attach the AMG8833 to the front of the TurtleBot using a bracket.
18) Complete the connections as shown in the 'Electronics System Architecture' Section 4 on the breadboard.
19) Attach the breadboard at the rear of the TurtleBot.

The height provides increased range for shooting the ping-pong balls. Mounting it on top also allows for our robot to be more manoeuvrable, and obstruction to the LiDAR is minimized. Although the centre of gravity is slightly elevated, this is not very significant as the weight of the shooting system is light relative to the weight of the TurtleBot.

4. ELECTRONICS SYSTEMS ARCHITECTURE

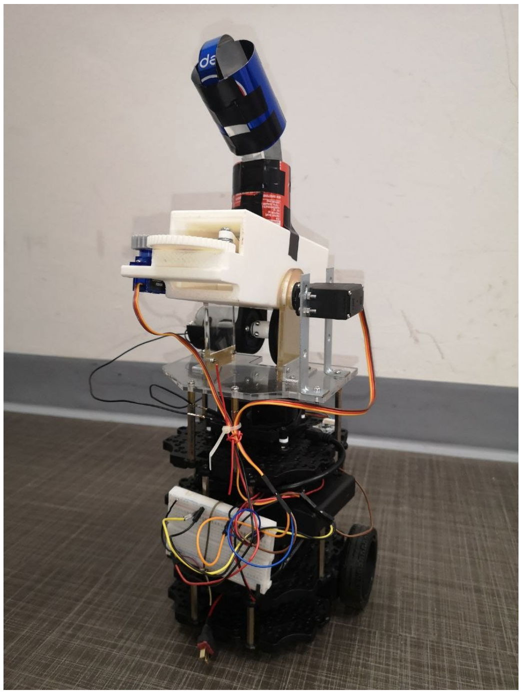


Figure 8: Electronic Systems on robot

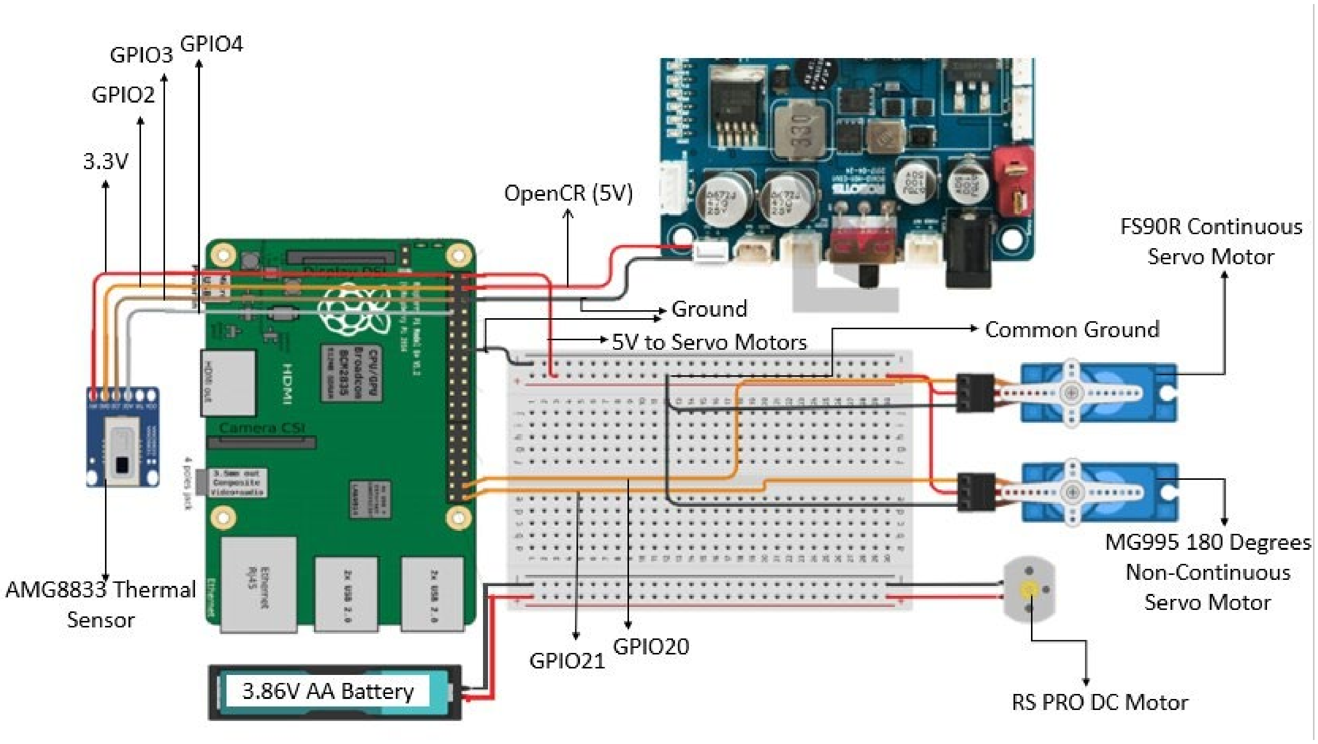


Figure 9: Electronics Systems Architecture

5. SYSTEM SPECIFICATIONS

5.1 Turtlebot3 Burger Specifications

The Turtlebot3 Burger specifications can be found at https://emanual.robotis.com/docs/en/platform/turtlebot3/features/

5.2 Firing System Specifications

Dimensions	15cm x 20cm x 23cm
Weight	755g
Ball Capacity	3 Ping-Pong Balls
Firing Range	2m
Tilt Angle Range	-10^{o} to 40^{o} from horizontal position
Flywheel DC Motor	RS PRO DC Motor Datasheet: https://docs.rs-online.com/8ee3/A700000007082033.pdf
Tilting Servo Motor	MG995R Servo Motor Datasheet: https://www.electronicoscaldas.com/datasheet/MG995_Tower-Pro.pdf
Crankshaft Servo Motor	FS90R Continuous Servo Motor Datasheet: https://www.tme.eu/Document/466f036ded06bd5cfbf8271c3502f528/POLOLU-2820.pdf
Thermal Sensor	AMG8833 Datasheet: https://cdn-learn.adafruit.com/downloads/pdf/adafruit-amg8833-8x8-thermal-camera-sensor.pdf

Table 1: Firing System Specification

5.3 Overall System Specifications

Dimensions	18cm x 20cm x 43cm
Weight	1412g

Table 2: Overall System Specification

5.4 Power Budget Table

This section provides the power consumption of a typical 30-minute run and the power budgeting of the system.

Component	Voltage supplied (V)	Current drawn(I)	Average Power Consumed (W)	Operating Duration(s)
Servo motor (Continuous)	5	0.000132	0.00066	3
Servo motor (Non-Continuous)	5	0.000568	0.00284	3
DC Motor	4.5	1.514	6.813	1800
Initial LiDAR turn	12	0.65	7.8	30
During Booting (Peak)	12	0.85	10.2	30
Moving	12	0.6	7.32	1800
Raspberry Pi Camera	3.3	0.25	0.825	1800

Table 3: Power Table

Li-Po battery power consumed per 30-minute run (Wh)	7.629002917
Li-Po battery capacity (Wh)	19.98
Maximum no. of runs	2

DC motor power consumption per 30-minute run (Wh)	3.4065
4x AA 1.5V Batteries capacity (Wh)	3.9
Maximum no. of runs	1

Table 4: Power Budget

6. GETTING STARTED

6.1 Boot-up

Ensure that the overall battery level is not below 11.1V. Please refer to Section 7.1.1 for the guide to check the Li-Po battery level. Connect the Li-Po Battery to the connector on the lowest level of the Turtlebot. Flip the switch on the OpenCR, a green light will be seen on the OpenCR, a melody will be heard and the LiDAR will begin spinning.

6.2 Connecting to the robot

A computer with Ubuntu Linux Focal Fossa (20.04) or other operating system supported by ROS 2 Foxy installed is needed. Please install ROS 2 Foxy on Ubuntu. Please refer to https://emanual.robotis.com/docs/en/platform/turtlebot3/quick-start/, section 3.1.2 'Install ROS 2 on Remote PC' for installation guide.

Once ROS 2 Foxy is installed, proceed to install packages and set the ROS environment. Refer to the same guide (https://emanual.robotis.com/docs/en/platform/turtlebot3/quick-start/), section 3.1.3 to 3.1.4 for installation guide. To configure environment, enter the following in the terminal in sequence without the prompt $. Note that the number 30 is arbitrary and must not clash with other ROS installations operating under the same network.

```
$ echo 'source ~/colcon_ws/install/setup.bash' >> ~/.bashrc
$ echo 'export ROS_DOMAIN_ID=30' >> ~/.bashrc
$ source ~/.bashrc
```

Follow https://emanual.robotis.com/docs/en/platform/turtlebot3/sbc_setup/#sbc-setup section 3.2.1 to create a bootable SD card with Ubuntu 20.04 installed. It is required to either,

- setup the wireless connection before booting (with available DHCP)
- Connect to an external monitor with HDMI cable
- Connect to wired network (with available DHCP)

To the Raspberry Pi (rpi), insert the SD card and connect to power to boot it up. Derive the IP address and use Secure Shell Protocol (ssh) to connect to it if using a network. Proceed with section 3.2.3 onwards in the same tutorial.

Follow https://emanual.robotis.com/docs/en/platform/turtlebot3/opencr_setup/#opencr-setup to install firmware onto the OpenCR.

On the device running the code, execute the following,

```
sudo apt install python3-pip python3-opencv
pip3 install scipy numpy
```

Note that this assumes that the default Python 3 will be used. The package management procedures might be different on other Python distributions such as Conda.

6.3 Calibration

Detach the MG995 servo motor from the firing system and calibrate. Please refer to *manual_tilt.py* in the [GitHub repository] for the code to calibrate the MG995 servo motor. Secure copy this file to the RPi over the ssh connection using the 'scp' command. Run the file by entering 'python3 manual_tilt.py' in the ssh terminal. When prompted by the terminal to enter an angle to tilt to, enter 90. Reattach the MG995 servo to the barrel with the barrel positioned horizontally. Then kill the code using ctrl + c.

6.4 Operation

Switch on the TurtleBot by following the instructions in the '6.1 Boot-up' section. Next, flip the switch on the battery holder connected to the flywheel motor. The flywheel will rotate while the robot is navigating.

6.4.1 Navigation and Mapping

Clone the GitHub repository locally onto where the code will be executed. First bring up the robot with,

```
ros2 launch turtlebot3_bringup robot.launch.py
```

After that, execute on the controlling computer,

```
ros2 launch turtlebot3_cartographer cartographer.launch.py
```

to launch the SLAM mapping nodes and verify that the rviz window correctly reflects the current visible environment. Then execute the `nav.py` file with python3 and the navigation should be starting automatically. Use Ctrl-C to terminate the process when desired.

6.4.2 Target Identification, Aiming, and Firing

From the same repository from the calibration portion, find the *aiming_algorithm4.py* file. Secure copy this file to the RPi over the ssh connection as well. Run the file from the ssh terminal by entering

```
python3 aiming_algorithm4.py
```

This file should execute simultaneously with the navigation file and will communicate with the navigation node to tell it to stop when the target is detected and continue when the shooting task has been completed. When the shooting task has completed, this file will finish running.

7. BATTERY

7.1 Li-Po Battery

Figure 10: Li-Po Battery

7.1.1 Checking Li-Po battery levels

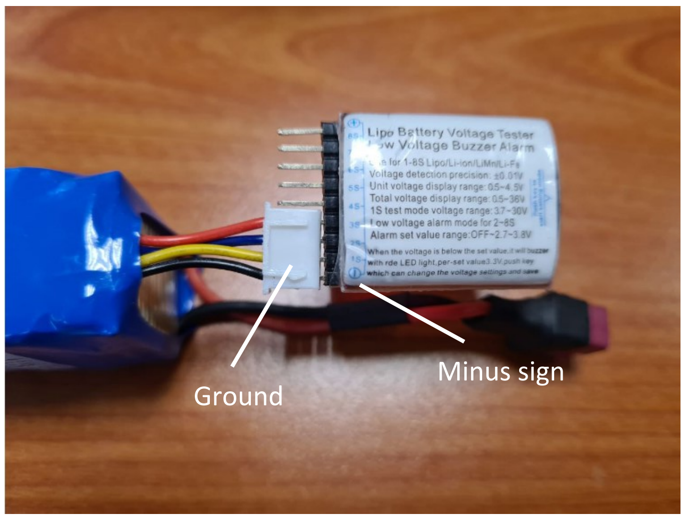


Figure 11: Li-Po Battery with Battery Tester

1) Use the LiPo Battery Voltage Tester Low Voltage Buzzer Alarm to check for the battery level.
2) Ensure that the Ground (Black) cable on the Balance Lead is connected to the pin with ‘minus’ symbol on the voltage tester as shown in *Figure 11*.
3) A loud beep will be heard when connected correctly.
4) Check for the voltage level on the battery tester screen
5) Disconnect the battery tester from the Balance Lead.

** ‘ALL’ shows the voltage across the entire battery; 1, 2, and 3 shows the voltage across the first, second, and third cell of the battery. Nominal voltage for ‘ALL’ is 11.1V, which means the battery needs to be charged. Nominal voltage for each cell is 3.7V. Please ensure that the voltage levels for each cell is similar, with difference of ±0.2V only. If the voltage difference between cells are greater than 0.2V, please stop usage and dispose the battery.

7.1.2 Charging Li-Po Battery

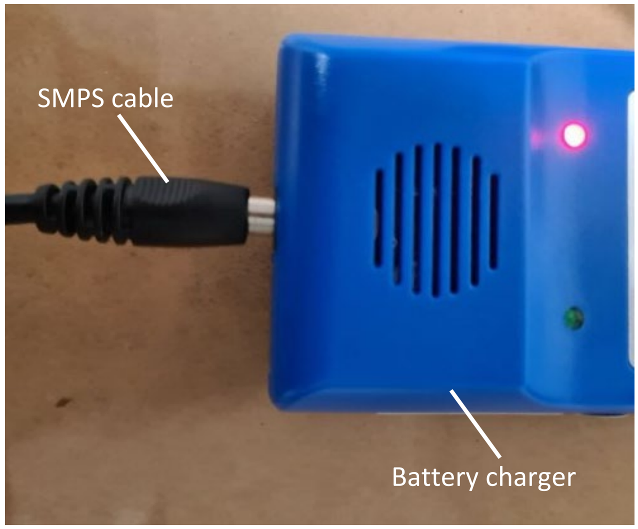


Figure 12: SMPS connected to battery charger

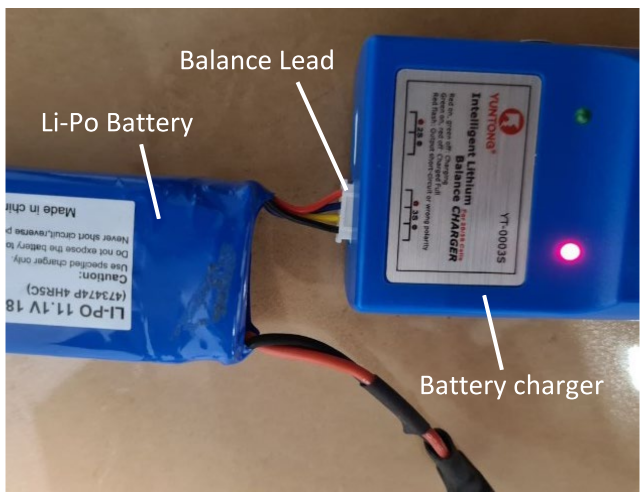


Figure 13: Balance Lead connected to battery charger

1) Connect the Switched Mode Power Supply (SMPS) to the battery charger (LBC-010).
2) Connect the Balance Lead to the battery charger with the correct polarity. A red light will be lighted when charging.
3) A green light will be lighted when it is fully charged. Disconnect the Balance Lead and check the battery level to ensure balance charging.

APPENDIX

Parts List

Item	Quantity	Weight (g)
LiDAR	1	112
Waffle layer 4	1	40
Layer 3 standoffs front	1	13.2
Layer 3 standoffs middle	1	13.2
Layer 3 standoffs rear	1	13.2
Raspberry Pi Model 3B+	1	48
Lidar adapter board	1	2
Waffle layer 3	1	40
Layer 2 standoffs front	1	13.2
Layer 2 standoffs rear	1	13.2
Open CR	1	67
Waffle layer 2	1	40
Layer 1 Standoffs front	1	10
Layer 1 Standoffs rear	1	10
Battery	1	9
Motors and Wheels	1	83
Waffle layer 1	1	40
USB Top	1	6
USB Bottom	1	6
Battery Cable	1	9
Total Weight		588

Table 4: Turtlebot3 Burger Parts List

More details of the Turtlebot3 Burger parts can be found at https://emanual.robotis.com/docs/en/platform/turtlebot3/features/#specifications

Location	Item	Quantity	Weight (g)
Identification	AMG8833 Thermal Sensor	1	4
	Metal Bracket	1	5
	M3 nylon nuts x2 M3x10 nylon screw x2 M3 Nuts x2 M3x10 Screws x2	1	5
Pitching Mechanism	MG995R Non-continuous servo motor	1	48
	Servo Horn	1	5
	Metal L-Bracket	2	4
	M3 Nuts x6 M3x10 Screws x6	1	4
Ball feeding Mechanism	Reloading barrel	1	10
	3D-printed crankshaft system	1	31.5
	3D printed large gear	1	
	3D printed small gear	1	
	FS90R Continuous Servo Motor	1	11.5
	Metal Plate	1	4
	M4 washer x4	1	6
	M4x10 Screw x1 M5x20 Screw x1 M5 Nut x1	1	4
Firing Mechanism	RS Pro DC Motor	1	152.5
	3D printed coupler part	2	8
	65 mm diameter wheel	1	15
	DC Motor Holder	1	22
	M2.5x15 Screw x5 M2.5x20 Screw x3 M3x5 Screw x2 M2.5 Nut x7	1	14
Others	Barrel	1	106.5
	Barrel Support	2	29
	Acrylic Plate	1	65
	Metal Bracket	3	15
	Brass Stand-offs 50mm x4 M3x10 Screws x8	1	36
	Battery Holder with 3 AA batteries	1	139
	Breadboard	1	80
Total Weight			895

Table 5: Firing System Parts List

CAD Files for Payload

STL files for crankshaft mechanism (pusher head, crankshaft, and gears), barrel, couplings, and DC motor mount are found in the following link. This link also includes the STEP files for the acrylic base and the FINAL CAD of the payload.

https://drive.google.com/drive/folders/1QuUE31cCNMq9R3jTvY3d6Do7UPaP2HPo

Software Documentation Link

https://github.com/SuibianP/r2auto_nav/tree/snowy-owlcat-patch-1