RMIT UNIVERSITY

School of Engineering

Design Report

Advanced Mechatronics System Design – MANU2451

Team Members:

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Problem Statement

The S.T.A.L.K.E.R inspection robot is Factorio Engineering's latest attempt to advance the current market of house inspection devices. Current-day inspection robots, such as the very popular GPK-32 by SuperDroid robots, are used to conduct inspections of areas around homes and buildings typically unreachable to humans due to a myriad of constraints. These constraints can range from size restrictions or inhospitable environments. Through the use of remote-operated robots, these previously hard-to-reach areas are now accessible. Once deployed the main prerogative of the standard inspection robot is to obtain and send video footage, preferably live footage, to the operator for further human analysis. The engineering team at Factorio Engineering plans to look into furthering this standard model with the additions showcased through the S.T.A.L.K.E.R.

The S.T.A.L.K.E.R aims to introduce a level of automation to the operation process in the form of obstacle avoidance and warning systems. This will allow operators to more acutely focus on camera controls and analysis hopefully resulting in a higher quality of the inspection. Additionally, the maneuverability of the S.T.A.L.K.E.R is a key consideration. The mecanum wheels utilized in the design allow the device to make tight movements while achieving a range of motions not achievable by standard wheels or tracks. Furthermore, additional data collection in the form of mapping will be conducted. Mapping through the use of lidar will allow users to make more informed decisions and allow for information gained from inspections, such as wall limits and obstacles, to be archived and reused.

Due to the typical environments, these machines are operated in many constraining factors, other than simply space limitations are present, which affect the methods of sensing and operation that are chosen. Noise pollution and dark environments can make certain sensors not optimal as well as uneven or dirty environments causing mechanical issues. All these factors as well as time have been considered when determining the scope of objectives attempted by the team in the development of the S.T.A.L.K.E.R.

In summation, the inspection robot put forth aims to:

1. Introduce automation or semi-autonomous systems.
2. Achieve superior maneuvering
3. Conduct mapping

Note: *Factorio Engineering team is our MANU2451 group name, and S.T.A.L.K.E.R is the team's robot design name.*

Proposed Design

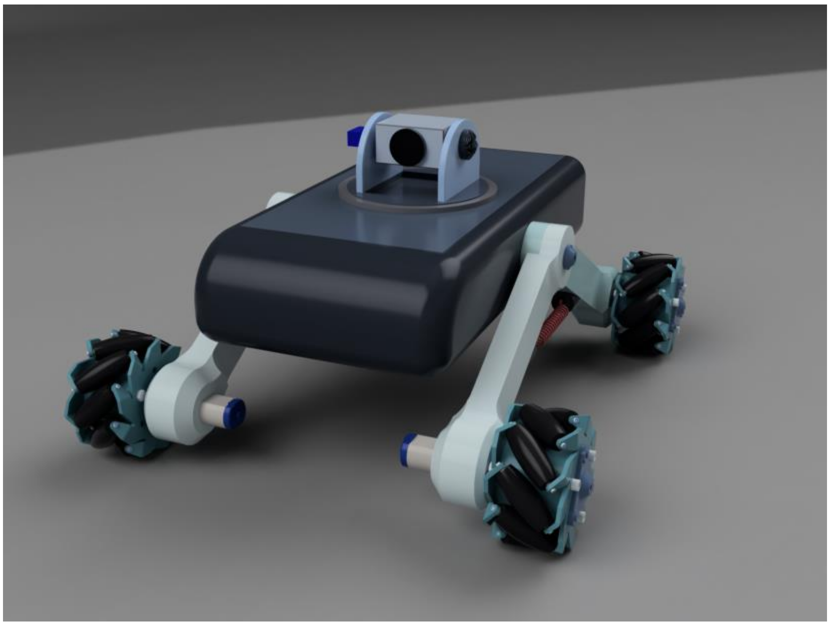


Figure 1. Rough 3D sketch/concept of the inspection robot (S.T.A.L.K.E.R).

In this project, the design and implementation of an inspection robot are proposed. The 3D model of the proposed inspection robot is shown in Figure 1 and the figures below.

The purpose of designing this robot is to semi-autonomously navigate indoor or outdoor premises, a house for example, and send video streams to a base station for visualization and recording purposes.

Note: The base station could be a local or remote location where users can view video streams from the robot, and or store the recording for future reference. It could be as simple as a laptop.

Functionality

Motion/Mechanical Systems

Functionality	Description
Omnidirectional motion (Mecanum Wheels)	Utilize the advantage of the Mecanum wheels that allows for more freedom of movement. Each wheel will be powered by NEMA17 44Ncm stepper motors or 6-12 DC motors with a speed encoder. Hence, wheels are programmable where it rotates in certain patterns.
Ability to move on uneven ground (outdoor environment)	Rover-like legs, with spring in between which will retract legs on the left or right-hand side when moving on uneven ground.
360° camera rotation on the x-axis	The motion allows the camera to look at the front, back, left, and right, which is controlled by a stepper motor (28BYJ-48 or NEMA17

	13Ncm). The decision for the stepper motor will be decided after more research and evaluation.
0° - 90° camera rotation on the y-axis	The motion that allows the camera to look up and front, which is controlled by a servo motor (SG90)
Ultrasonic sensors	Part of the obstacle avoidance system (HC-SR04).

Table 1. Motions/mechanical system functionalities

Data Acquisition

Functionality	Description
Temperature and humidity reading	The robot will record humidity and temperature from the surroundings and transmit these to a "base station".
Video recording and stream	Video recordings of the surroundings are captured and broadcasted to a base station for the user to view live streams of the surroundings, or to record.
Lighting to assist in video capture	To assist the cameras in capturing videos in darker environments, lighting is used.
IR video recording and streaming	The normal cameras are not able to get proper capture behind the walls for example. In these cases, it's best to use an IR camera.
Gas sensors	To detect if the area is exposed to poisonous gasses, a gas sensor can be used.

Table 2. Data acquisition functionalities

Communication

For the communication from the rover to a base station, wireless communication is used due to the flexibility of coverage. The common use of 2.4 GHz frequency and in different wireless protocols such as Wifi, Bluetooth, Zigbee, etc makes it an ideal choice for this project.

Due to the RF nature, the signals could get lost in an underground space for example. In these cases, a communication relay can be used, or the robot is required to perform the surveillance on its own and then record the data which can be transmitted into the base station once the robot is in the wireless range.

Components

Mechanical Parts and Motion Systems

Engineering Drawings

Below are the engineering drawings of the design with its component.

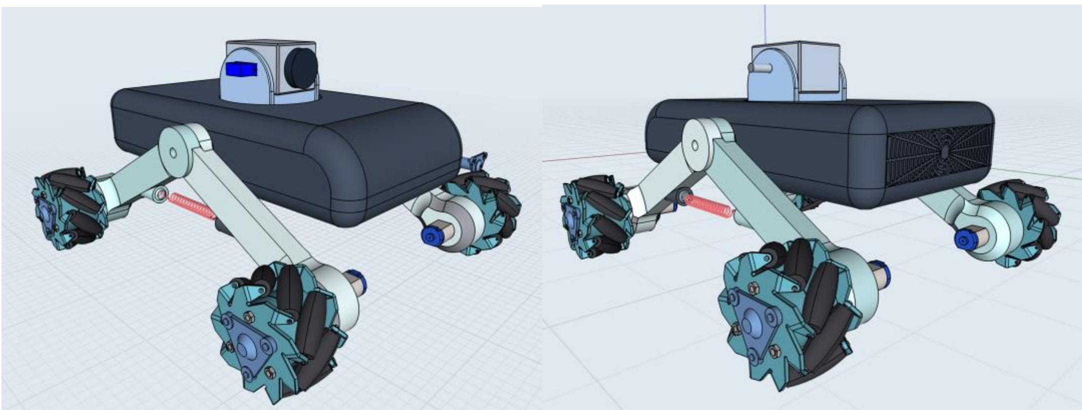


Figure 2. Isometric front and back views of the chosen design

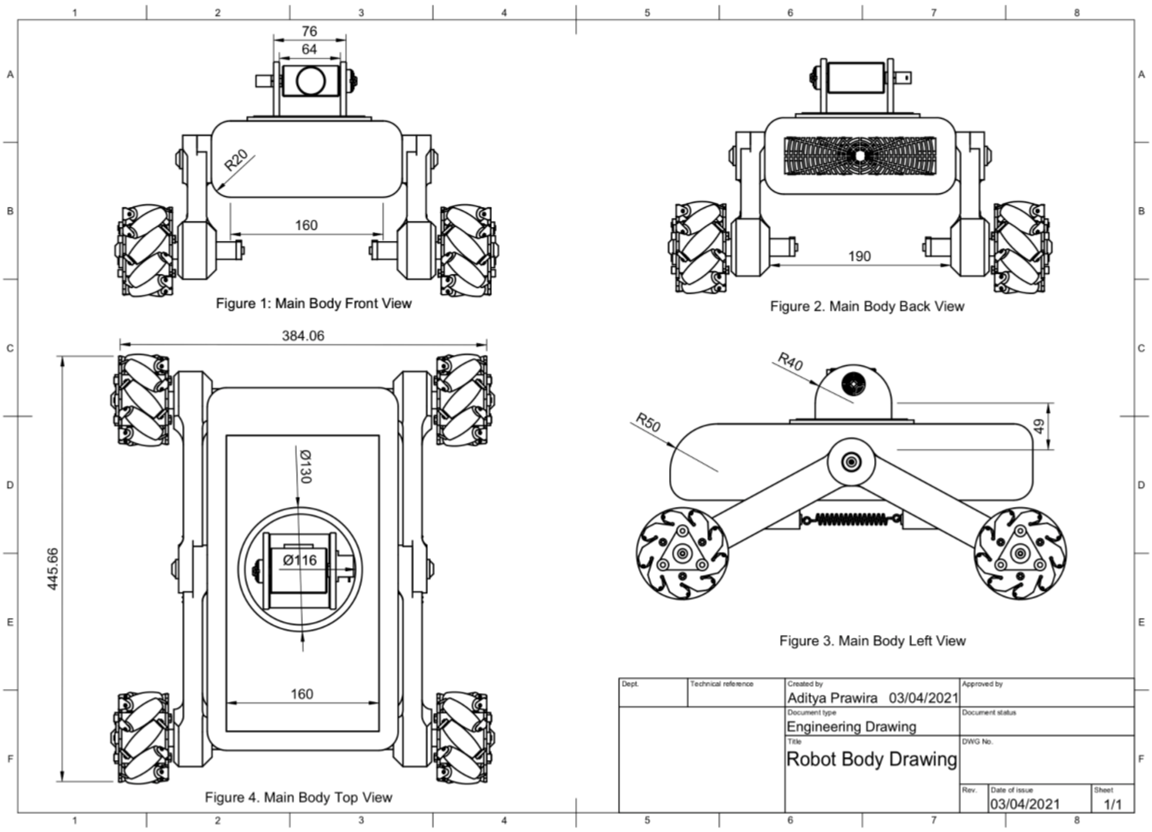


Figure 3. Engineering drawings of the proposed design

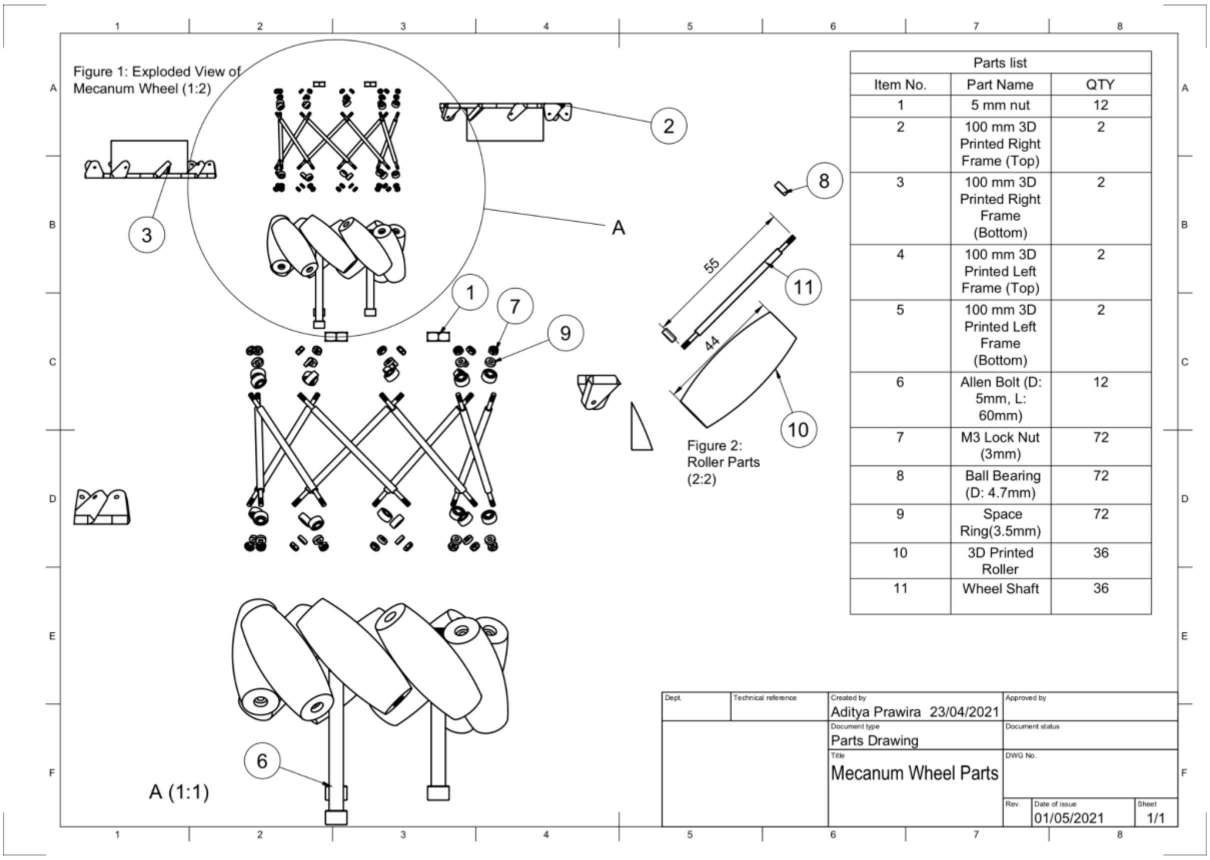


Figure 4. Mecanum Wheel parts

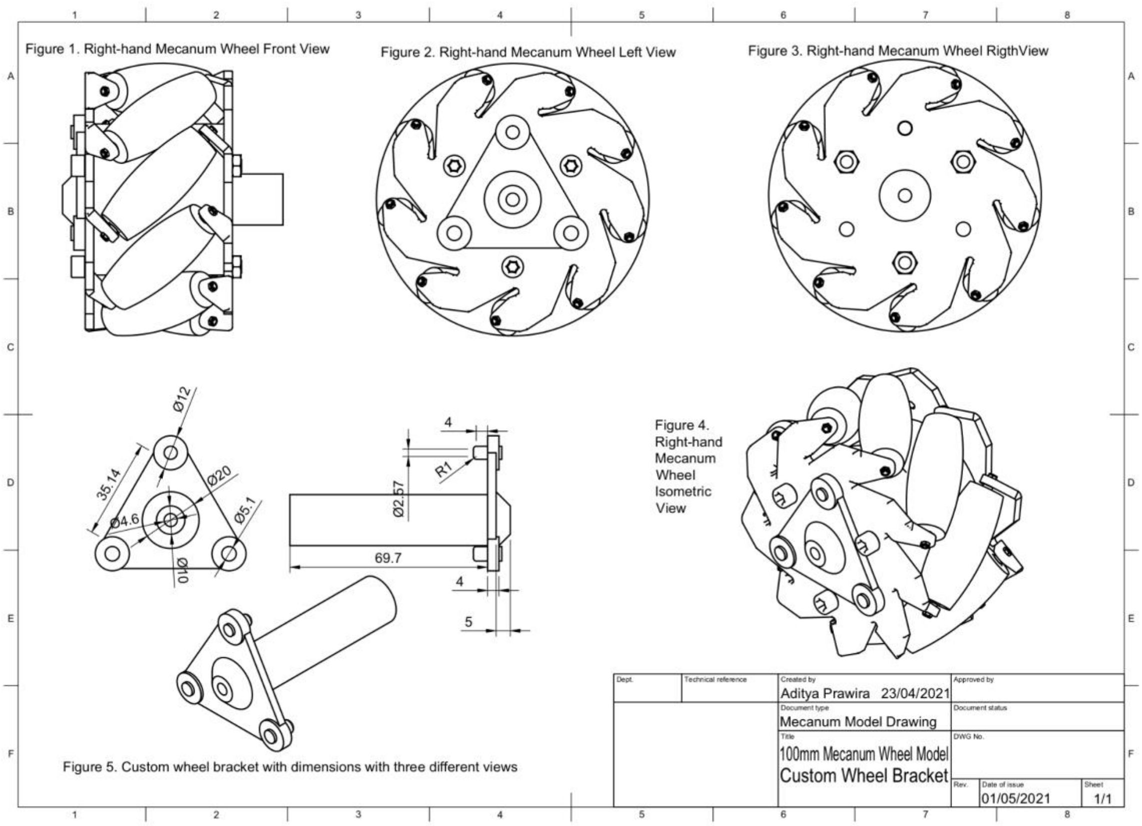


Figure 5. Right-hand mecanum wheel drawings with different views

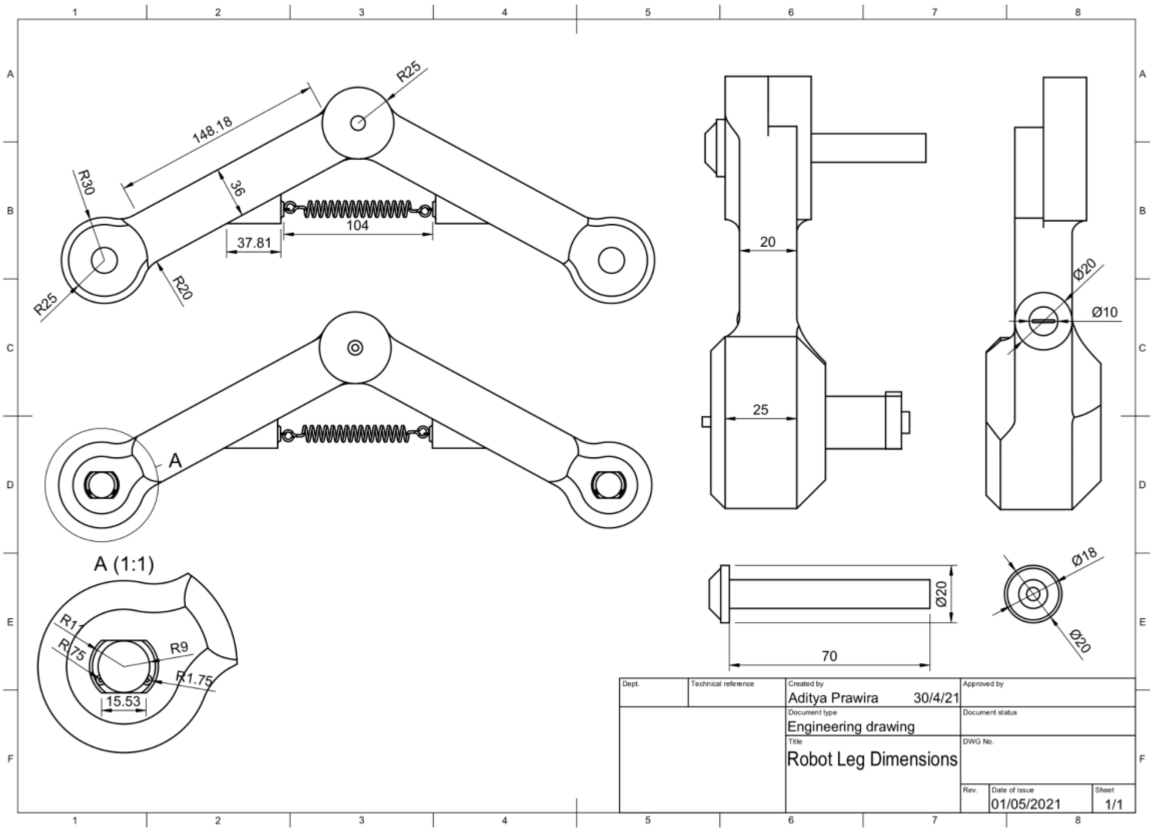
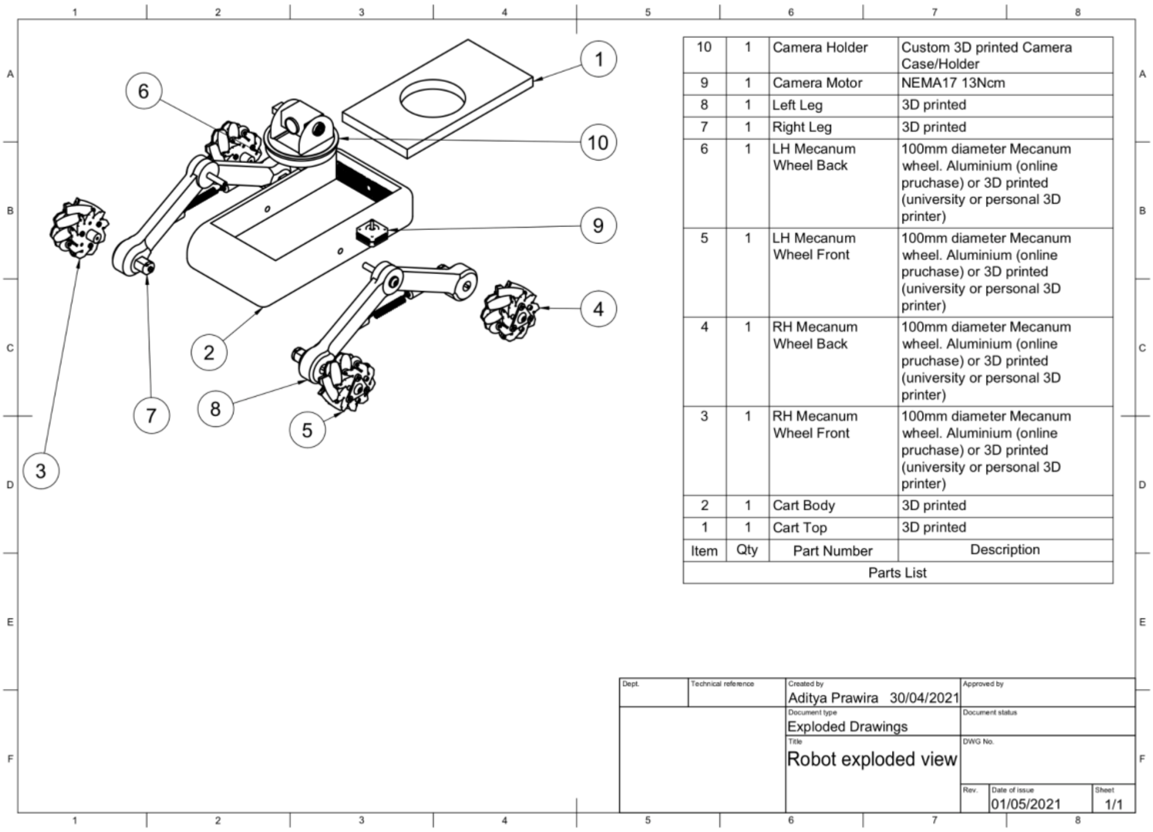


Figure 6. Robot leg engineering drawings



Item	Qty	Part Number	Description
10	1	Camera Holder	Custom 3D printed Camera Case/Holder
9	1	Camera Motor	NEMA17 13Ncm
8	1	Left Leg	3D printed
7	1	Right Leg	3D printed
6	1	LH Mecanum Wheel Back	100mm diameter Mecanum wheel. Aluminium (online pruchase) or 3D printed (university or personal 3D printer)
5	1	LH Mecanum Wheel Front	100mm diameter Mecanum wheel. Aluminium (online pruchase) or 3D printed (university or personal 3D printer)
4	1	RH Mecanum Wheel Back	100mm diameter Mecanum wheel. Aluminium (online pruchase) or 3D printed (university or personal 3D printer)
3	1	RH Mecanum Wheel Front	100mm diameter Mecanum wheel. Aluminium (online pruchase) or 3D printed (university or personal 3D printer)
2	1	Cart Body	3D printed
1	1	Cart Top	3D printed

Parts List

Figure 7. Robot body exploded view

Figures 5 and **6** represented the engineering drawing of the right-hand mecanum wheel, and the right leg of the robot. The left-hand mecanum wheel and the left leg of the robot will have the same dimensions as what has been shown in Figures 5 and 6, however, the only difference is that the orientation of all its subcomponents will mirror the drawings above.

The utilization of the tension spring between the robot leg, as shown in **Figure 5,** is meant to retract the leg to its normal condition or equilibrium position whenever it rolls over an object such as rocks or when the robot operates on an uneven ground condition. In **Figure 6**, the detail drawing labelled as **A(1:1)** represents the space where the team will plant the DC motor of the wheel.

As shown in **Figure 5 - 7**, the robot body, legs, wheel brackets, and the camera holder are all 3D printed. However, for the mecanum wheels, the team has two options. Since it is based on an existing product, then option 1 would be to purchase the full set of the mecanum wheels online and it is based on Aluminium or option 2, where the team will 3D print the model (with university's 3D printer or personal 3D printer) and manually assembled each wheel and purchases the required bolts, locks, and nuts. Therefore, the decision of the wheel will depend on how the team views the budget. Furthermore, the stepper motor for the camera in the current drawings utilizes the NEMA17 13Ncm model.

NOTE: *The design dimensions of the design and the decision of the stepper motor for the camera may differ in the final design and report due to design optimization processes before the deadline.*

Motion Operation

The diagram shown in **Figure 8** below represents movements that can be done by the robot by utilizing the mechanism of mecanum wheels.

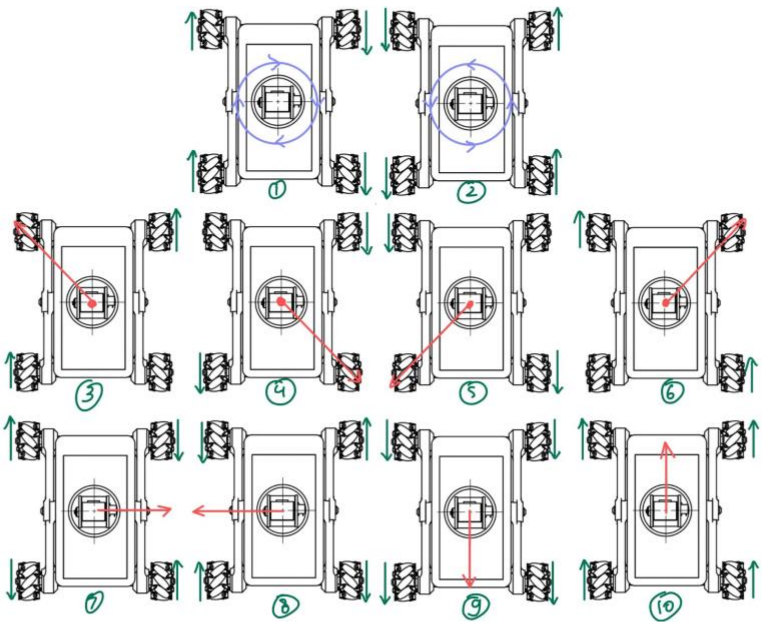


Figure 8. Robot motion operations

Motion Label	Description
1	Clockwise rotation
2	Anti-clockwise rotation
3	Forward-left motion (45°)
4	Downward-right motion (45°)
5	Downward-left motion (45°)
6	Forward-right motion (45°)
7	Motion to the right
8	Motion to the left
9	Backward motion
10	Forward motion

Table 3. Robot motion descriptions for **Figure 8**.

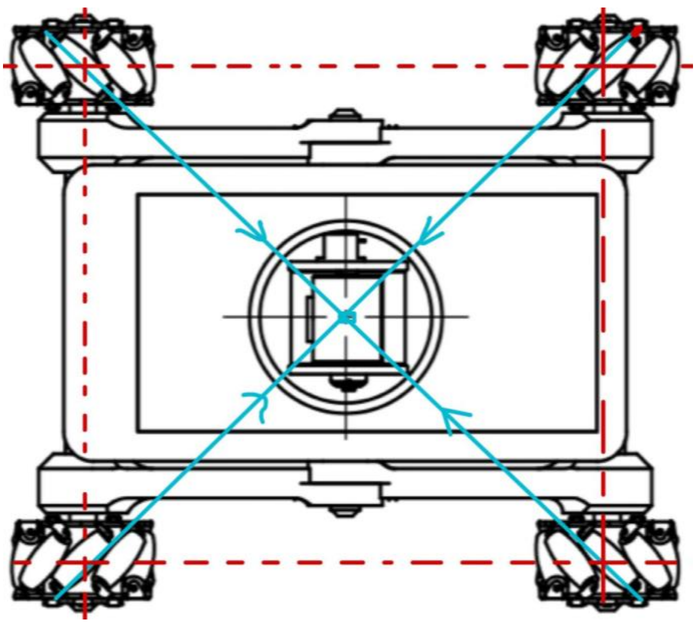


Figure 9. The rollers of mecanum wheels are directed towards the centre of the robot.

Notice, by the chosen dimension of the robot, it is shown in **Figure 9**, that the rollers of the mecanum wheels are directed towards the centre point of the robot which indicates the rotation axis of the whole robot's body or its centre of inertia. Hence, by convention, it explains how the motion *numbers 1 and 2 as* shown in **Table 3** can be executed where the robot able to rotate in a clockwise or anti-clockwise direction while maintaining its centre position.

At this stage, let's consider the motion diagram of the robot shown below.

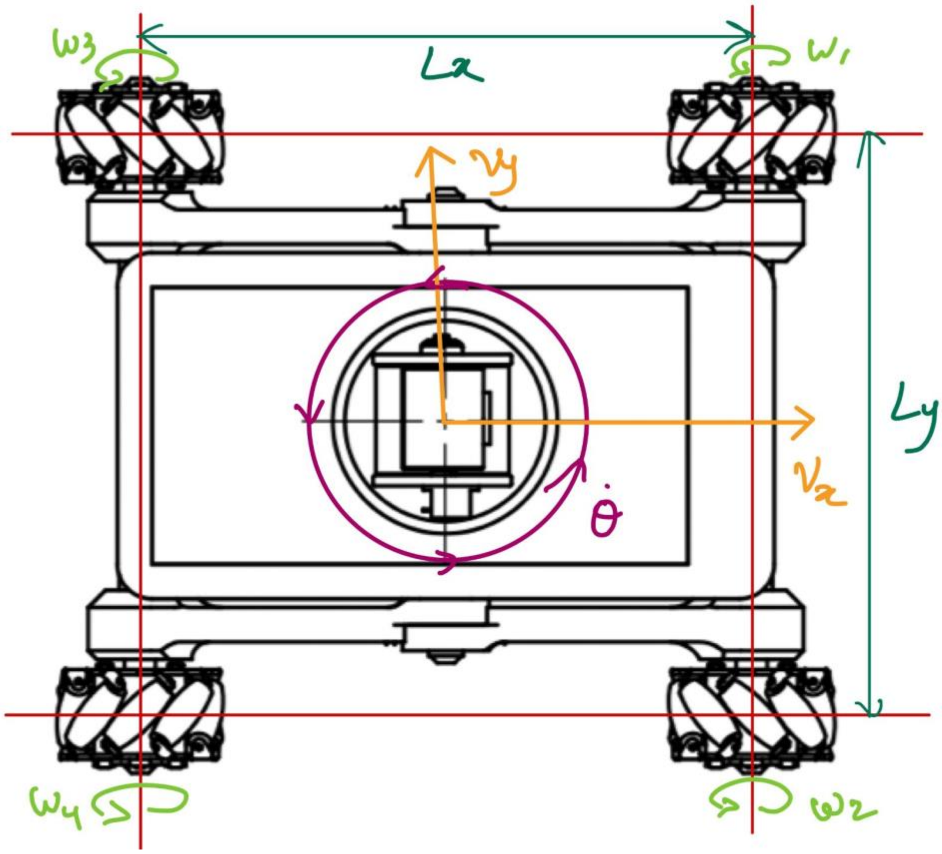


Figure 10. Robot model diagram

Based on the figures above, it is modelled that the input would be the angular rotation from the DC motor from each wheel, where those inputs would produce outputs of the robot's linear and rotary motions.

It is defined that motion equations of the utilization of mecanum wheels will be represented as shown below (Taheri, Qiao, and Ghaeminezhad 2015) :

- Forward kinematics of the robot's motions will be

$$\begin{bmatrix} v_x \\ v_y \\ \omega \end{bmatrix} = \left(\frac{R}{4}\right) \begin{bmatrix} 1 & 1 & 1 & 1 \\ -1 & 1 & 1 & -1 \\ \frac{-2}{L_x+L_y} & \frac{2}{L_x+L_y} & \frac{-2}{L_x+L_y} & \frac{2}{L_x+L_y} \end{bmatrix} \begin{bmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \\ \omega_4 \end{bmatrix}$$

- As the inverse kinematics equation would be modelled as

$$\begin{bmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \\ \omega_4 \end{bmatrix} = \begin{bmatrix} 1 & -1 & \frac{-(L_x+L_y)}{2} \\ 1 & 1 & \frac{(L_x+L_y)}{2} \\ 1 & 1 & \frac{-(L_x+L_y)}{2} \\ 1 & -1 & \frac{(L_x+L_y)}{2} \end{bmatrix} \begin{bmatrix} v_x \\ v_y \\ \omega \end{bmatrix}$$

Where ω_1, ω_2, ω_3, and $\omega_4$represented the angular velocity produced from each DC motor of the wheel, which is the variable inputs. As the constant inputs will be R (radius of mecanum wheel), L_x, and L_y shown in **Figure 10**. The aforementioned angular velocities are variable and hence customizable. Therefore, it indicates that the angular velocities tuned accordingly to achieve the desired speed, and the desired motion the team would want the robot to execute. On the other hand, it can be another way around where the team targets the expected v_x, v_y, and $\omega$to design the velocities to be produced/done by the DC motors.

The figure below will represent the input-output or the interaction of how the angular rotation would be processed to achieve motions listed in **Table 3**.

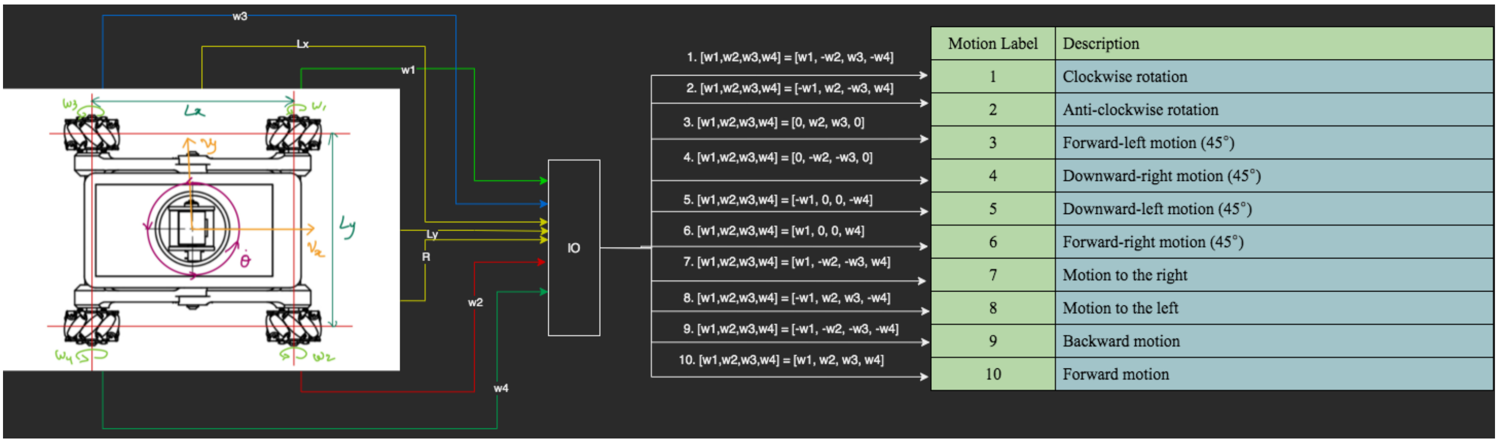


Figure 11. Input-Output system of motion.

Electrical and Communication

The block diagram below explains the electrical and electronic components of the system and their interconnections. Sections below will address each of the components in detail.

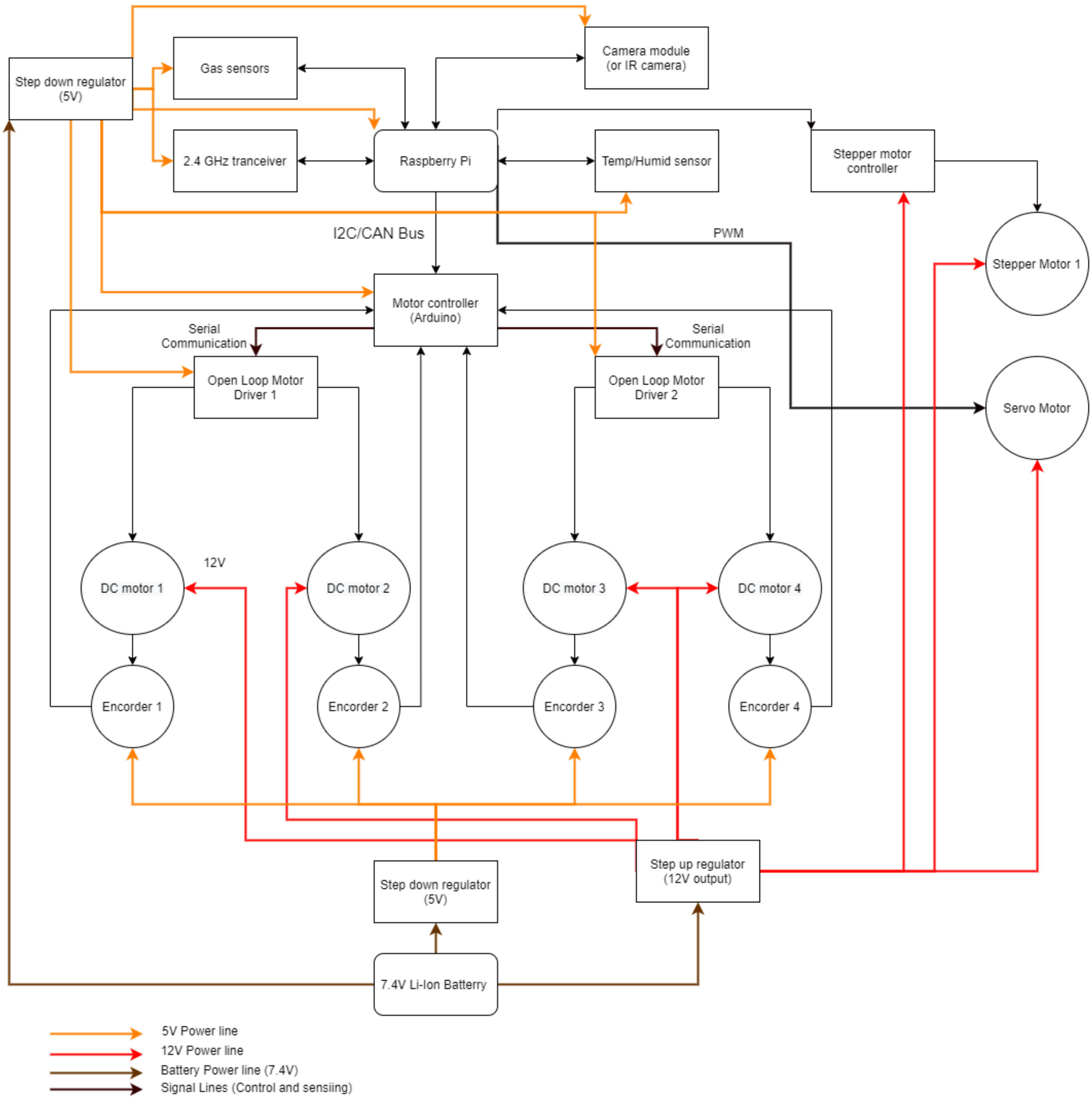


Figure 12. Internal hardware interactions.

Control

DC Motors

This project utilizes four 12V DC motors with 770RPM, from Pololu motor manufacturer, to drive the robot. Having an embedded quadrature encoder is an advantage to this motor since this can be used to drive the robot more precisely by sensing its direction, amount of rotation, and RPM.

DC Motor controllers

The motor controllers have three parts, the motor driver, feedback sensing, and control signal generation. For the motor driver part of the motor controller, two "Pololu Qik 2s9v1 Dual Serial Motor Controller" will be used to drive the four motors. The Raspberry Pi can interface with the motor driver through a serial communication (RS232) interface. The encoders of the motors mentioned above, output a 5V square wave signal [Ref1]. These signals from each motor can be read through a microcontroller dedicated to the motor control operation, for example, an Arduino. Then the closed-loop control system will be implemented on this microcontroller.

Ref1: https://www.pololu.com/product/4862

Stepper Motors

For the camera gimbal of the design, a 28BYJ-48 stepper motor will be used. This will be used to rotate the camera in full 360° rotation in the x-axis as mentioned in the functionality section. For the 90 degrees rotation in the y-axis, and SG90 servo motor will be incorporated.

Stepper Motor Controller

The stepper motor, 28BYJ-48, will be controlled through a separate controller and the control signals will be issued by the raspberry pi. The controller board is based on ULN2003 motor driver from Texas Instrument. This module usually comes together with the 28BYJ-48 stepper motor. The stepper motor, SG90, will be controlled directly by the raspberry pi via PWM signals. There is no need for a control board since it's already built into the servo motor.

Sensor system

Temperature and humidity reading

The temperature and humidity sensor used in this design is the DHT22 sensor from Adafruit. This sensor is capable of reading temperature from -40 to 80-degree Celsius and humidity from 0-100% with good accuracy. Its communication using a single GPIO pin makes it easy to interface with Raspberry Pi. In addition, there are python libraries already available to use with raspberry pi, reducing the development time.

Video recording and stream

For the video recording and streaming, a raspberry pi camera will be used. This is a 8MP camera which can operate 1080p @ 30FPS. Also, this camera provides an easy interface to raspberry pi and provides sufficient specifications for the project.

Lighting to assist in video capture

The "LISIPAROI LED Camera Light for Raspberry Pi" will be used with the Raspberry Pi camera module to assist capture videos in darker environments. This module is also controlled through raspberry pi to enable and disable the lighting when required. This module uses LED lights as the light source which is low power and provides enough brightness. However, currently, this module can only turn on and off the light to its full brightness and completely turned off. Further research will be conducted to determine a module that can adjust the brightness.

IR video recording and streaming

To capture infrared thermal images, to get thermal info behind a wall, for example, MLX90640 Thermal Camera will be used. This camera module is low resolution, 24x32px, however, this is sufficient for detecting any temperature abnormalities in the area. This module will also be mounted with the camera module to allow rotation in the x and y direction, to capture a larger area.

Gas sensors

Few different gas sensors will be incorporated into the design. Firstly, a flammable gas and smoke sensor (MQ-2) to detect any flames and smokes from a current or past incident. Secondly, a Carbon Monoxide Gas Sensor (MQ-7) will be used to detect any toxic carbon monoxide gases in the area. These scissors will directly be interfaced with Raspberry Pi. Any other gas sensors can be incorporated into the design as required.

Communication system

For the RF communication system, a WiFi module, ESP32 will be used. This module will act as a WiFi hotspot and a server broadcasting video via RTSP protocol or any other real-time video transfer protocols. On the receiving end, a device such as a laptop can be used to simply connect to the network of the robot and view the video by connecting to a network broadcasting address.

Power system

Battery

At this point of the project, it is decided to use a 7.4V Li-Ion battery for powering the robot since it is safe in comparison to a Li-Polymer battery. It is believed that this battery will provide enough power to the system. However, future research will be conducted to determine the most appropriate battery. In choosing the battery several factors such as capacity, the current draw will be taken into consideration.

Voltage regulators

The components of the system will be operating at either 12V or 5V. Therefore proper voltage regulation is required to properly operate these components. For 12V, a step-up regulator will be used to boost the voltage from 7.4V to 12V. For the 5V, a step-down regulator will be used to regulate the voltage from 7.4V to 5V. Depending on the power requirements, the selected regulators (mentioned in the budget section) might be changed in the actual design.

Risk Analysis

In a separate subsection, explain what are the risks involved in your design. What can cause it not to fulfil its tasks completely? What sort of problems and challenges do you reckon may occur during implementing, testing, and finalizing your system built based on this proposed design?

Overheating – Due to restrictions in ventilation which will be discussed later, overheating could be a concern. Due to the device's mecanum wheel set up and their method of operation, 5 separate motors are required, 4 for the wheels and 1 for the camera. This coupled with the remaining parts, such as the gas and humidity sensor, etc. as well as an enclosed body could run the risk of elevated temperatures to the point of damage. Research into innovative forms of ventilation or cooling will need to be looked into if the presented risks are deemed too high.

Debris resistance – Due to the environment the device operates within, there are large risks in terms of contaminants such as dust and dirt as well as debris like weeds and glass interfering with the robot's operation. Dirt and dust can clog the operating systems of the device as well as being detrimental to any exposed interior elements. To protect against this any form of ventilation, if applied, would need to filter out dirt and dust particles to ensure that interior circuitry is protected. A solid chassis is being investigated as well as minimally exposed wire incorporated in the design to protect against debris.

Rough terrain - Though the mecanum wheels utilized in the design allow for superior mobility they are known to struggle on rough terrain. Since the operating environment for a device such as an inspection robot can contain obstacles and rough terrain this may present an operating concern, especially with the tight spaces that are present. One method utilized to overcome some of this issue is the inclusion of a tension spring on the legs of the robot. This addition will provide the device with the ability to traverse over small inclines and obstacles.

Noise pollution – Concerns have been raised, as to the level of noise pollution that might be in operating environments. These could be in many forms from moving obstacles such as loose coverings, animals or debris as well as sound pollution such as occupants, animals, and music. To ensure the best performance out of our product least susceptible sensor type to the common noise pollution in those areas was chosen. It was determined that ultrasonic sensors would function best as obstacle avoidance systems and would perform well against the pollution and natural constraints of the environment.

Loss of signal – Wireless communication would provide a large range of coverage as well as flexibility in its range of protocols and portability. However, in underground or environments of a certain size and material composition, the risk of signal loss is a reality. If communication between the operator and the device is broken, the inspection robots' main purpose of recording and relaying information would be impossible. Furthermore, retrieval of the robot once lost could be a hazard due to the inaccessibility as well as the dangers present in the work environments, such as gasses, exposed wires, and tight spaces. To help avoid this, a communication relay could be implemented to act as an information broker between the robot and the base station/operator.

Camera damage – The camera acts as the eyes of the operator, and the chief instrument utilized during the inspection process. If easily blinded, miss-aligned, or damaged the camera's vulnerability would become a detriment to its goal. To protect against this, simple to remove and clean covers will be placed on the cameras, as well as a sturdy mounting plate to ensure the best performance from the attachment. A secondary concern related to the camera feature is memory storage for the footage taken. The available memory onboard the device could not be sufficient which may require the use of a 3rd party storage location for the video data.

Sensor range – Though long-distance sensing may not be as impactful to the device's performance, the minimum range of utilized sensors might cause issues in obstacle avoidance. This issue presents itself on two fronts. Firstly, the device may show an inability to detect new obstacles below its minimum sensor range. This presents the risk of the robot getting caught or blocked in by obstacles/terrain. However, through the use of a bumper sensor or other form of short-range sensing this risk could be mitigated. Secondly, the possibility to not sense some small obstacles while traversing inclined terrain could be problematic as the sensor's direction changes as the robot inclines.

Sensor volume – Typically, gathering as much information as possible is a positive outcome, however, care must be taken to not overwhelm the system with too many processes and inputs. Thus, with the mecanum wheels operating system already being complex along with the variety of data points and live camera feed needed for the inspection process additional operations would be well advised to stay within reason if not to a minimum. If the microcontroller used is overloaded or inefficiently coded, some processes might delay others, resulting in delays and missing data samples, and damaging the real-time nature essential to the device.

Plan B – Apartment Package delivery device (APDD)

An inconvenience present in the lives of many people who live in apartment buildings is mail. Whether packages, letters, or bills a resident would typically need to travel to their lobby or talk with a staff member to receive their mail. The APDD seeks to remove this inconvenience by taking packages and mail directly to the door of the recipient from the lobby. With the addition of a reflective sensor and a QR scanner, our device could be adjusted to fit this premise. The already implemented gas and humidity sensor could relay temperature data to residents along with gas warnings through Wi-Fi. A strip of reflective tape and QR codes relating to apartment locations would be installed on the floors and used to help guide the device and allow it to be fully automated. However, there are some glaring issues with this product that would need further development before such a solution is functional. If knocked off of its course the device might not be able to recover and navigate itself back on track. Furthermore, as time passes, damage or markings on the reflective tapes and QR codes signifying apartments would result in navigation difficulties if not a complete breakdown of the entire system.

Project Management

	Weeks										
Task	2	3	4	5	6	7	8	9	10	11	12
Selecting Robot											
Robot designs concept											
Design proposal											
Design realistic robot dimensions											
Simulation (CAD)											
Design Report											
Simulation (Simulink and MATLAB)											
Presentation											
Final report											

Figure 13. Gantt chart of the project

Deliverables

Task	Description
Selecting Robot	Choosing one out of many robot ideas (vacuum cleaner, robot arm, etc.)
Robot designs concept	Conceptualizing and refining the inspection robot design.
Design proposal	Submitting a proposal for the inspection robot project.
Design realistic robot dimensions	Modifying the robot's dimensions to better suit the small spaces that the robot should encounter during an inspection.
Simulation (CAD)	Create a 3D cad model of the inspection robot for the simulation.
Design Report	Submit a report about the selected robot that details the design process and the purpose of the robot.
Simulation (Simulink and MATLAB)	Create a simulation of the robot maneuvering around an environment and mapping its surroundings.
Presentation	Present the inspection robot project and the simulation of the inspection robot performing a set of tasks.
Final report	Write a report that will summarise the design process and outcomes of the project.

Table 4. Task descriptions table

Budget

Item	Supplier	Qty.	Unit Price	Total Price	Purchase Link
Motor DC12V 770RPM with encoder	Pololu	4	$44	$176	https://www.pololu.com/product/4862
DC Motor driver	Pololu	4	$32	$128	https://www.pololu.com/product/1110
DHT22 Temp and humid sensor	Adafruit	1	$13.00	$13.00	https://www.adafruit.com/product/385
Raspberry Pi camera	Core Electronics	1	$39	$39	Click Here
Raspberry Pi Camera LED Light ring (LISIPAROIIR-01)	Element14	1	$35	$35	Click here
MLX90640 Thermal Camera	Core Electronic2	1	$125	$125	Click here
MQ2 Gas sensor	Pololu	1	$6	$6	https://www.pololu.com/product/1480
MQ7 Gas sensor	Polulu	1	$10	$10	https://www.pololu.com/product/1482
ESP32 WiFi communication moule	Core Electronics	1	$34	$34	Click here
7.4V 1200 mAh Li-Ion battery	Aus Electronics Direct	1	$25	$25	Click here
Step down regulator	Aus Electronics Direct	2	$5	$10	Click here
12V Step-Up Voltage Regulator U3V70F12	Robot Gear	1	$15	$15	Click here
28BYJ-48 stepper motor and driver module	Phipps Electronics	1	$10	$10	Click here
SG90 Servo motor	Jaycar	1	$12	$12	Click here
Mecanum Wheel 100mm set of 4	Amazon	1	$64	$64	Click here
Grand Total				AUD$ 702	

Table 5. Budget table

Team Work

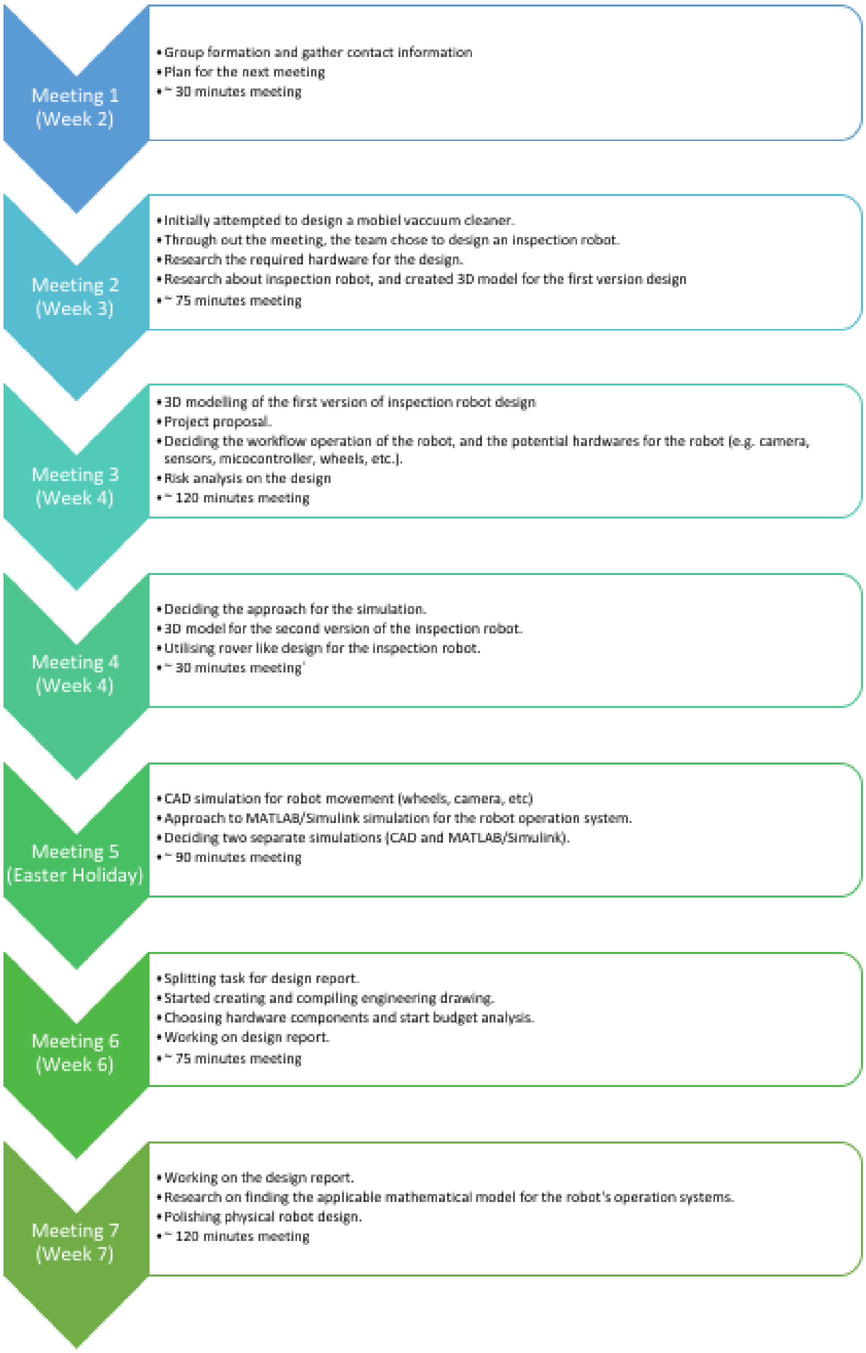
Members Name	Role Description
Aditya Prawira	Team Leader and also responsible for the robot design, and its mechanical/motion operation.
Ibrahim Yusuf	Responsible for managing the project and is deliverability
Mewantha Kaluarachchi	Responsible for electrical and communication components for the robot and budgeting.
Nadir Ince	Responsible for literature research and risk analysis of the project

Table 6. Team member roles

References

[1] Taheri, H., Qiao, B. and Ghaeminezhad, N., 2015. Kinematic Model of a Four Mecanum Wheeled Mobile Robot. International Journal of Computer Applications, 113(3), pp.6-9.

Attachment



Component	Datasheet/Specs
Motor DC12V 770RPM with encoder	https://www.pololu.com/product/4862/specs
DC Motor driver	https://www.pololu.com/product/1110/specs
DHT22 Temp and humid sensor	https://www.adafruit.com/product/385
Raspberry Pi camera	https://www.raspberrypi.org/documentation/hardware/camera/
Raspberry Pi Camera LED Light ring (LISIPAROIIR-01)	http://www.farnell.com/datasheets/3207714.pdf
MLX90640 Thermal Camera	To find specs for this module, Click here
MQ2 Gas sensor	https://www.pololu.com/product/1480
MQ7 Gas sensor	https://www.pololu.com/product/1482
ESP32 WiFi communication module	https://cdn.sparkfun.com/assets/learn_tutorials/8/5/2/esp32-wroom-32_datasheet_en.pdf
7.4V 1200 mAh Li-Ion battery	To find specs for this module, Click here
Step down regulator	To find specs for this module, Click here
12V Step-Up Voltage Regulator U3V70F12	To find specs for this module, Click here
28BYJ-48 stepper motor and driver module	To find specs for this module, Click here
SG90 Servo motor	To find specs for this module, Click here
Mecanum Wheel 100mm set of 4	To find specs for this module, Click here