A VISION BASED ROBOTIC ARM FOR SEWER MAINTENANCE

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A Final Year Design Project (FYDP) submitted to the Department of Electrical and Electronic Engineering in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical and Electronic Engineering or Bachelor of Science in Electrical and Communication Engineering

Department of Electrical and Electronic Engineering
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Declaration

It is hereby declared that

1. The Final Year Design Project (FYDP) submitted is my/our own original work while completing degree at Brac University.
2. The Final Year Design Project (FYDP) does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The Final Year Design Project (FYDP) does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
4. I/We have acknowledged all main sources of help.

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Approval

The Final Year Design Project (FYDP) titled "A Vision-Based Robotic Arm for Sewer Maintenance" submitted by

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of Spring, 2025 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Bachelor of Science in Electrical and Electronic Engineering on 15th May, 2025.

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Ethics Statement

We hereby declare the following:

1. The material is solely the original work of the stated authors, prepared under the supervision of the aforementioned Academic Technical Committee panel members.
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Abstract/Executive Summary

Our project introduces a cost-effective, vision-assisted robotic system for safer and more systematic sewer maintenance. For ages, manual sewer cleaning has exposed workers to toxic environments filled with various health hazards. Our robotic arm will be using a camera and a 3 Degree of Freedom (DOF) arm to detect and remove sludge, reducing human intervention. It offers real-time monitoring and a remote control system for increased safety and ease of operation. Our innovative solution fully supports sustainable sanitation practices and will be specifically suitable for urban infrastructure in developing regions.

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Chapter 1: Introduction [CO1, CO2, CO10]

1.1 Introduction

In Bangladesh, and especially in urban areas such as Dhaka, sewer cleaners working by hand face dangerous and potentially lethal working conditions, as they are exposed to toxic gases, the threat of asphyxiation, contaminated matter, and a range of related health risks. Such inadequacies of the country's sewer systems, with around 78% of Dhaka not being able to provide for proper stormwater drainage, only compound these problems. Waterlogging is a common result of blockages in the sewers, leading to serious public health and environmental problems [1]. Workers frequently encounter health issues due to insufficient safety protocols and a shortage of protective gear, as manual labor remains one of the few available options[2].

This project, a vision-guided robotic arm, aims to automate sewer upkeep to address these pressing issues. The robot, equipped with a camera and a 3-degree-of-freedom arm, is capable of identifying and extracting sludge from sewer systems, thereby reducing the need for human intervention in hazardous environments [1]. This groundbreaking system seeks to enhance the safety of workers by reducing their exposure to harmful materials while simultaneously increasing the effectiveness of sewer maintenance within urban infrastructure. The project aims to deliver a cost-efficient and sustainable option for Bangladesh, especially in city areas with inadequate sewer systems, by incorporating advanced engineering tools and contemporary technologies into a feasible, deployable system.

The vision-based assistive robot is therefore a technological innovation that tackles health and safety risks confronted by sanitation workers and improves sewer maintenance. Unlike traditional manual approaches that are time-consuming and prone to human errors, this robot provides an automated system that enables accurate detection and removal of plugs [2]. The system is designed to work efficiently in the challenging conditions of sewers by using advanced technologies, including a low-light camera and a three-degree-of-freedom robotic arm. This project seeks to define the baseline for the introduction of robotics in urban sanitation, particularly in developing regions with some of the industry's greatest challenges, including lack of infrastructure and worker safety.

1.1.1 Problem Statement

Thousands of sanitation workers in Bangladesh regularly face hazardous conditions, toxic gases, and pathogens due to manual sewer maintenance. As this further leads them to serious health risks and fatalities, inefficient drainage systems in Dhaka aggravate waterlogging, requiring a safer, automated solution.

1.1.2 Background Study

Bangladesh has been employing a large number of sanitation workers, with research suggesting that around 5 to 6 million workers are exposed to various forms of manual sanitation labor, as well as sewage cleaning [3]. Despite providing a crucial service, these workers face severe and unsafe working conditions that expose them to hazardous health risks and lack legal protection. These workers are mostly underpaid, and the insufficient access to safety equipment makes them vulnerable to respiratory diseases, sometimes with lethal accidents leading to death [3].

The capital city, Dhaka, spreads to a total area of 360 sq. km under the authority of the Dhaka Water Supply and Sewage Authority (ASA). But 78% of this area lacks a stormwater drainage system. During the monsoon season, this factor contributes heavily to the city's waterlogging problem [1]. The entire Dhaka division, which covers an area of 1,528 sq. km, also faces similar challenges. The surface drains, with an area of 1,500 km, are often clogged with solid waste, construction debris, etc., displaying inefficiency. In lower-class, densely populated areas, this blockage of stormwater drains leads to severe waterlogging that hampers daily life, bringing health hazards into the lives of regular people [2].

1.1.3 Literature Gap

Solutions involving robotics for sewer inspection and cleaning have shown committed results addressing these challenges around the world. One of them is the Sewer Inspection Autonomous Robot (SIAR), which helps to examine large sewers, uncover structural defects, and reduce human involvement [4]. Another one is the Tunnel Inspection Robot developed in Singapore, which uses high-resolution cameras and sensor arrays to detect blockages and monitor the structural probity of large-diameter sewers or tunnels [5]. A sewage waste removal robot was also built in India with an arm and most of the 3D-printed parts to decrease the necessity of human labor in dangerous environments [6]. Despite advancements in robotic sewer inspection systems globally, there are significant gaps when it comes to applying these technologies in developing countries like Bangladesh. The SIAR robot and similar platforms, while effective, are costly and designed for well-developed infrastructure [6]. These technologies are less adaptable to the unique challenges of Bangladesh, where infrastructure is poorly maintained and often manually operated.

1.1.4 Relevance to Current and Future Industry

Evidently, from the literature review conducted to assess the design requirements it has been noted that 3D modeling of the robotic parts, kinematics and dynamics simulation, structural analysis (stress-strain withholding capability), payload capacity and power requirement calculation, control architecture (using microprocessors or microcontrollers to individually activate each actuator and motor when necessary), and reliable communication protocol establishment are some of the most essential analyses required to assess the feasibility and productivity of the design approaches so as to compare between them. Among these, 3D modeling and the establishment of communication protocols are essential frameworks for both approaches. Integration of ROS (Robotic Operating System) is also mandatory for the seamless operation of the robotic arm control, although that is to be undertaken later in the completion phase, since it requires hardware integration.

The development of a vision-based assistive robot for sewer maintenance seeks to address these gaps by providing a cost-effective solution that is adaptable to varying infrastructure dimensions suited for deployment in Bangladesh while helping to establish a safer working condition. As the blockages in sewers remain the main causes for flooding and disruption of daily life, our project aims to decrease manual labor dependence, enhance worker safety, and overall tackle this serious pressing issue around the country.

1.2 Objectives, Requirements, Specifications, and Constants

1.2.1 Objectives

The primary objectives of our project in developing a Vision-Based Assistive Robot for Sewer Maintenance are:

1. Locate and remove blockages or clogs in sewers to ensure efficient drainage.
2. Minimize health risks by reducing human intervention in hazardous sewer cleaning tasks.
3. Perform inspections and maintenance to prevent the buildup of debris and recurring clogs.

By implementing this technology, we aim to reduce the dependency on manual labor in hazardous environments and improve the efficiency of sewer maintenance. The robotic arm will enhance worker safety by minimizing direct exposure to harmful chemicals, toxic gasses, and dangerous pathogens commonly encountered in sewage. The system will ensure continuous monitoring and timely intervention, preventing future blockages and reducing the frequency of costly repairs and waterlogging. This technology will be particularly relevant in cities like Dhaka, where frequent blockages and inadequate sewer infrastructure contribute to health and environmental problems. The robotic arm will offer a scalable, efficient solution that can be adapted for use in both developing and developed urban areas.

1.2.2 Functional and Nonfunctional Requirements

TABLE 1.1: FUNCTIONAL AND NON FUNCTIONAL REQUIREMENTS

Requirements	
Functional	**Non-Functional**
Water Resistance	Toxicity Sensing
Detection of sedimentation/clog	Current sensing
Ensure adequate visibility underground	Graphic User Interface for Control
Ability to withstand sewage flow	Adaptable to different Sewer Dimensions
Adequate waste retrieval mechanism	
Provide real-time video feed for inspection	

1.2.3 Specifications

Design specifications:

i. . Load Capacity: ±5kg
ii. Dimensions (width): ≤80cm
iii. Visibility: Low Light Camera
iv. Video feed latency: ≤200ms

TABLE 1.2: HARDWARE COMPONENTS AND SPECIFICATIONS

Hardware Components	**Model**	**Specification**	**Comments**
IP Camera	TP-LINK VIGI C340i	Mega Pixels: 4.0 Resolution: 2560 x 1440 Lens: 2.8mm NightVision Viewing Angle: 106.5 degree Power: 5W Weight: 200gm Dimensions: 73 x 174 x 71 mm	Main Vision Component.
Linear Actuator	Long Stroke Linear Actuator	Operating Voltage: 12V Max Force: 900N Speed: 10 mm/s Stroke Length: 200mm Weatherproofing: IP65	Actuator for Link 2

		Weight: 1.355kg Dimensions: 32 x 10 x 5 cm	
DC Motor	37GB-545	Operating Voltage: 12V Speed: 195RPM Current: 1-5 Amps Weight: 0.290 kg Dimensions: 12 x 5 x 5 cm	Motor for End Effector
Stepper Motor	Nema 23HS5628	Current: 2.8A Step Angle: 1.8 degree Phase: 2 Weight: 0.805 kg Dimensions: 16 x 14 x 12 cm Holding Torque: 12.6 kg-cm	Motor for Base Rotation
Stepper Motor Driver	TB6600	Power: 160W Micro Step: 1,2/A,2/B,4,8,16,32 Weight: 0.2kg Dimensions: 96 x 56 x 33mm	Driver for Stepper Motor
Motor Driver	BTS 7960	Voltage: 6-27V Max Current: 43A Dimensions: 50 x 50 x 43 mm Weight: 67 gm Frequency: 25kHz	Driver for both Linear Actuator and DC Motor
Inertial Measurement Unit	MPU 6050	Operating Voltage: 3-5 V Communication: I2C Dimensions: 3 x 2 x 1cm Weight: 0.01 kg	Measures angles at all joints
Microcontroller	Arduino UNO	Operating Voltage:7-12V Flash Memory: 32KB Clock Speed: 16 MHz Dimensions: 14.5 x 9 x 2cm	Controlling Unit for all Motor Drivers
Single Board Computer	Raspberry Pi 4B	Processor: 1.5GHz 64-bit quad-core RAM: 4GB LPDDR4, Communication: 2.4GHz and 5.0GHz 802.11ac Wi-Fi, Gigabit Ethernet, Bluetooth 5.0, USB	Used to communicate with Base Station

Battery	Lipower	Capacity: 5500 mAh Discharge Rate: 35C Cells: 3S Dimension: 140 x 45 x 30mm Weight: 400g	Main Power Supply
Buck Converter		Power: 200W Input Voltage: 5-40V DC Output Voltage: 12-36V DC	Used for components requiring 5V DC
Boost Converter	DEVMO	Power: 600W Input Voltage: 10-60V DC Output Voltage: 12-60V DC Current: 10A	Used for components requiring 12V DC
Router	Xiaomi MI 3C	Frequency: 2.4GHz Speed: 300 Mbps	Used for communication between SBC and Base Station

1.2.4 Technical and Non-technical Constraints

TABLE 1.3: TECHNICAL AND NON TECHNICAL CONSTRAINTS

Constraints	
Technical	**Non-Technical**
Size and shape: Device must fit and be able to move easily inside sewer pipes	Visibility: Underground infrastructures are not well-lit, if at all, so the camera will face difficulty while assessing the environment
Exposed components: Components cannot be exposed to the sewage materials which might be corrosive	Corrosive environment: The protective casing of the device must be resistant against toxic substances
Signal attenuation: Layers of concrete can weaken signals significantly so wireless technology should be used with discretion	Underground sewage flow: The constant flow of sewage might make it difficult for the device to be stable while operating
Power Source: There will not be any available power outlet in the middle of the road so appropriate power sources should be arranged.	Power Durability: It must be ensured that the LiPo battery is charged sufficiently so that it does not run out of power in the midst of the operation.

1.2.5 Applicable Compliance, Standards, and Codes

The design of this project is based upon existing standards and code such as the IP rating for waterproofing, ISO standards for the development and use of robotics projects, ASTM standards for integrating corrosion-resistant materials, which helps in system protection from substances entering inside the robot during its operation inside sewers. Factory workers or floor-based operators are also deeply influenced by occupational safety standards, like those set by OSHA governing industrial environments.

The most relevant and applicable standards and codes are explained below:

ISO Standards

i) ISO 13355: Guidelines for mechanical handling of hazardous materials since the robot will be retrieving and transporting hazardous wastes.

ii) ISO 45001: Standards for occupational health and safety. It helps ensure worker safety when dealing with hazardous materials such as those retrieved by the robot

OSHA Standards (Occupational Safety and Health Administration)

i) OSHA 1910.146: This standard covers permit-required confined spaces, providing guidelines for working in confined environments like sewers, ensuring the robot's operation complies with safety requirements.

ii) OSHA 29 CFR 1910 Subpart S: Electrical safety requirements in potentially hazardous environments. Relevant for ensuring the electrical components of the robot are safeguarded in damp and hazardous conditions.

ASTM Standards

i) ASTM F2398-20: Standard for safety requirements for robotic systems in confined spaces. Sewer systems are confined spaces, and this standard applies to the operational safety of robots within such environments.

ii) ASTM A967: Standard for corrosion-resistant materials. Given the corrosive nature of sewage, components of the sewer waste retrieval robot should comply with this standard to ensure material durability.

1.3 Systematic Overview/Summary of the Proposed Project

The project develops a vision-based assistive robot for sewer maintenance, utilizing a robotic arm with a bucket end effector (Design Approach 1) to remove blockages. It employs low-light cameras, linear actuators, and wired communication (Ethernet/CAN Bus) for navigation and operation in sewers. Simulations using Fusion 360, MATLAB Simulink, Proteus 8 Professional, and Cisco Packet Tracer verified its kinematics, power efficiency, and communication reliability. The robot aims to enhance worker safety, reduce manual labor, and improve sewer system efficiency, with hardware implementation planned for the completion phase.

1.4 Conclusion

The vision-based assistive robot offers a cost-effective, safe, and efficient solution for sewer maintenance in Bangladesh, addressing critical health, safety, and environmental challenges. By leveraging advanced engineering tools and adhering to international standards, the project promises significant societal and industrial impact, paving the way for sustainable urban sanitation practices.

Chapter 2: Project Design Approach [CO5, CO6]

2.1 Introduction

To decrease the involvement of human workers in manual scavenging, one has considered that instead of human workers, a robotic system is to be established that would go into the sewer and take out the fecal sludge or waste material responsible for the clogging. So the problem can be divided into a few smaller problems.

a. One would need a system that was deployable in the sewer.
b. One would need to know the situation inside the manhole.
c. One needs to be able to take out the waste materials from inside the manhole to outside.

To solve the first problem, one would need either a robot or a pipe that can reach the depths of the manhole. A cross section of a typical manhole is shown below:

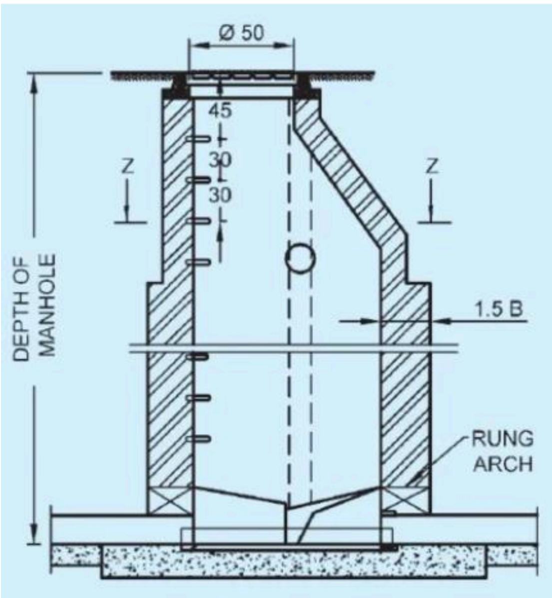


Figure. 2.1 Standard Manhole Dimensions[7]

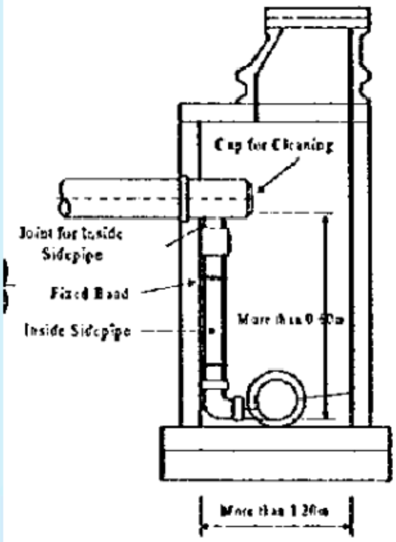


Figure. 2.2 Side Pipe Inside Manhole [8]

In the above figures, it can be seen that the size of the manhole is not constant. To reach the depth of the manhole, the system must be dynamic. This can be achieved by using a pipe or by sending a robot. However, given the system's interaction with fecal sludge and the considerable width of manholes, it faces significant challenges. So it needs to have the freedom to navigate in the XY axis too. For this specific reason, the idea of using retractable spider legs for navigation in the XY axis was proposed. The spider legs will have wheels at the end, and linear actuators will assist with their retractability.

Secondly, to completely understand or sense the environment inside a sewer, the system has to know the depth at which it is at and know about the presence of faecal sludge. Radars can measure sewer depth, but high-performance radars for confined spaces are costly. The only appropriate approach was using low-light cameras with a flashlight.

Finally, to take the fecal sludge or waste material out of the sewer, one can either use an excavator claw or use a pump to pump out the fecal material.

Upon solving these problems, next comes the problem of maintaining long range communication. One can opt for wired communication because the signal strength of wireless communication systems in confined spaces such as manholes are unreliable. Two possible ways to communicate are by using Ethernet cables or by using CAN Bus. CAN Bus or Controller Area Network Bus, is very efficient in long-distance communication using just two wires.

With all these in consideration, the following design approaches have been proposed. All the designs have the subsystems of power, control, communication, vision, and mechanical.

It is to be noted that at the preliminary stages of design, the optimal approach cannot be verified, as there is no data to prove how the design would perform.

2.2 Identify Multiple Design Approach

2.2.1 Bucket End Effector Approach

In Figure 2.3 we observe that, for power, a LiPo battery has been chosen which with buck and boost converters supply power to different subsystems. To ensure long distance communication ethernet cables are being used. For vision flashlights and a low light IP camera has been used. The control system mainly consists of a relay to control the actuators, a microcontroller and an SBC. The mechanical subsystem would consist of linear actuators to make the manipulator and spider legs for locomotion.

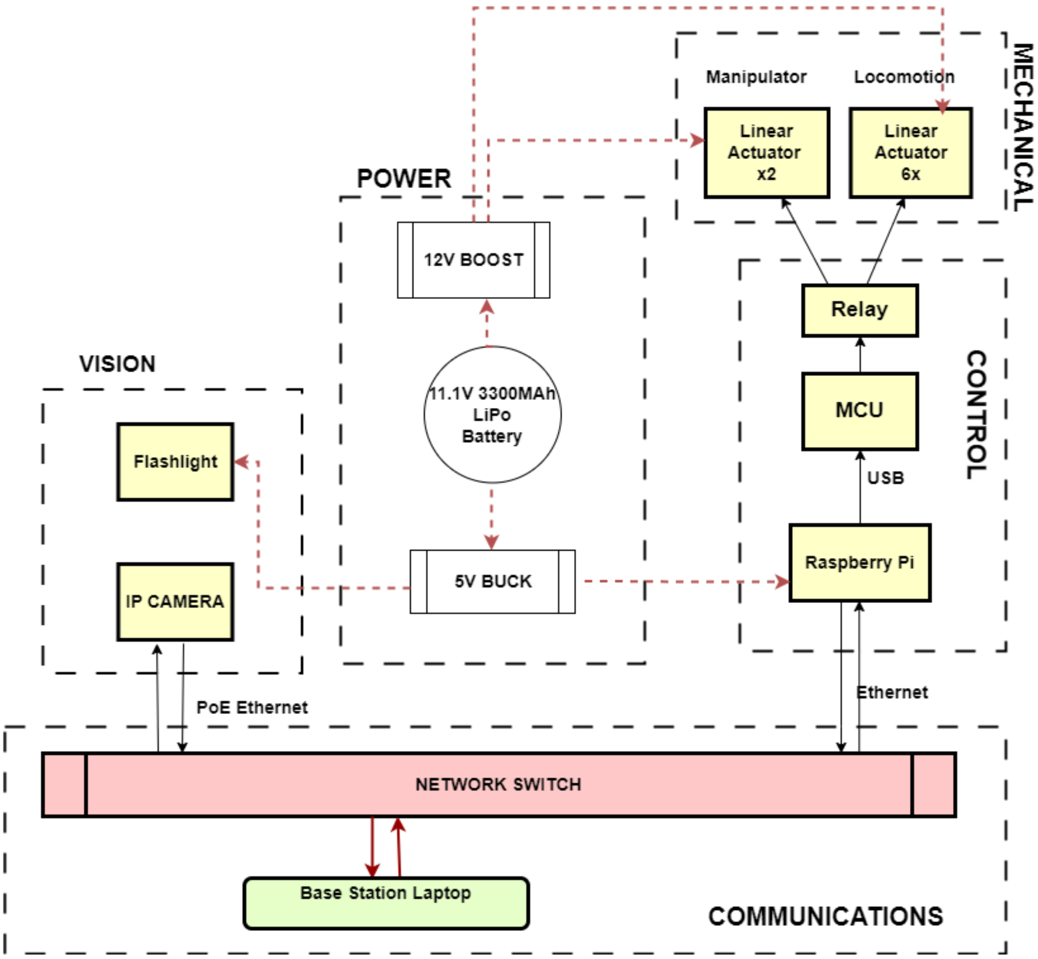


Figure 2.3 Block diagram of Design Approach 1

2.2.2 Vacuum End Effector Approach

In figure 2.3, we observe that, for power, a LiPo battery has been chosen, which, with buck and boost converters, supplies power to different subsystems. Moreover, a portable 3600W generator has been chosen for the pump. To ensure long distance communication ethernet cables are being used. For vision, flashlights and a low-light IP camera has been used. The control system mainly consists of a relay to control the actuators, a microcontroller, an SBC and a motor pump. The mechanical subsystem will include linear actuators for creating the spider legs used in locomotion, as well as a pipe head filter designed to collect waste.

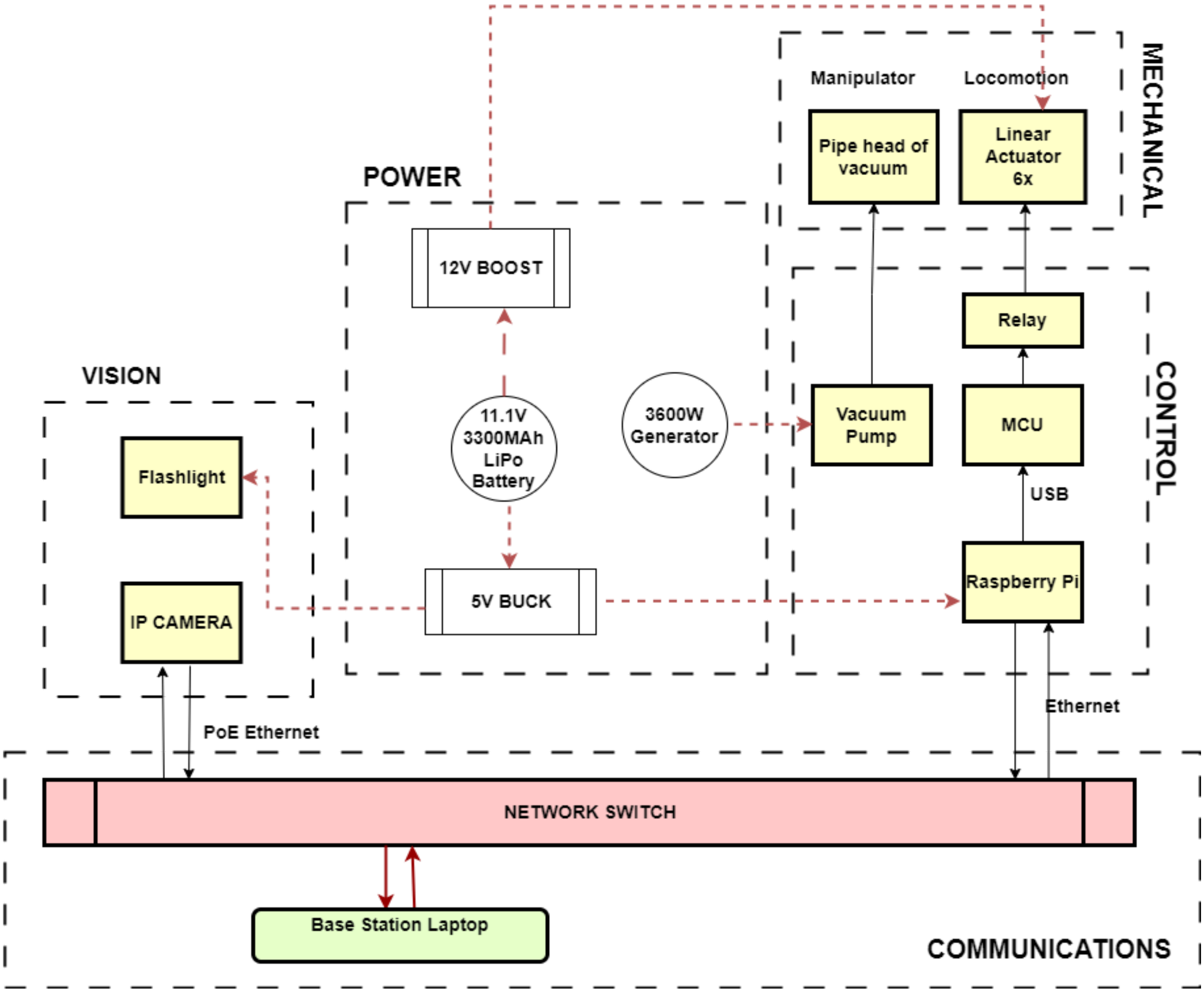


Figure. 2.4 Block diagram of Design Approach 2

2.3 Analysis of Multiple Design Approach

2.3.1 Kinematics and PID Control

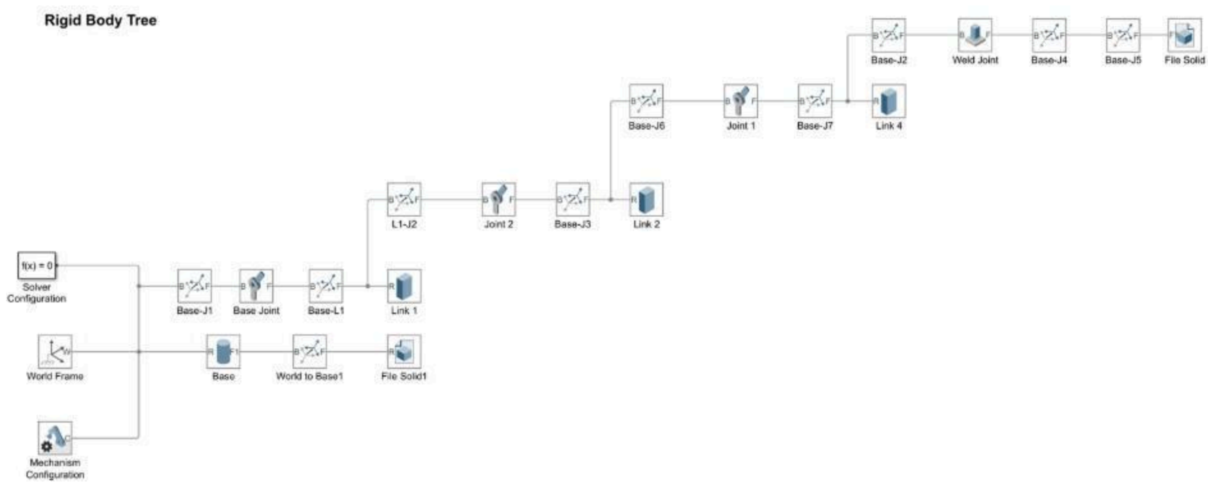


Figure 2.5 Simulink model of Arm Kinematics (3 Degrees of Freedom)

In figure 2.5, using MATLAB Simulink's rigid body tree framework, a 3-degree-of-freedom (DOF) robotic arm was designed to perform one translational and two rotational movements. The rigid body tree was meticulously structured to represent the robotic arm's kinematics. This setup enables precise control and prediction of the arm's movements using transformation matrices. Figure 2.6 shows the graphical model generated by Simulink based on the user created arm model.

The transformation matrix holds a crucial role in comprehending how the end effector retaliates to several joint angles. As the joints move, the model reveals the positional changes of the end effector with the help of matrices. In this way, we can be assured that every adjustment in the joint conFigureuration corresponds to a proper calculation of the end effector's position and inclination.

The model also supports both inverse and forward kinematics. Through forward kinematics, we can calculate the end effector's position given a set of joint angles. Therefore, the robotic arm achieves both accuracy and flexible movement by utilizing this comprehensive kinematic modeling.

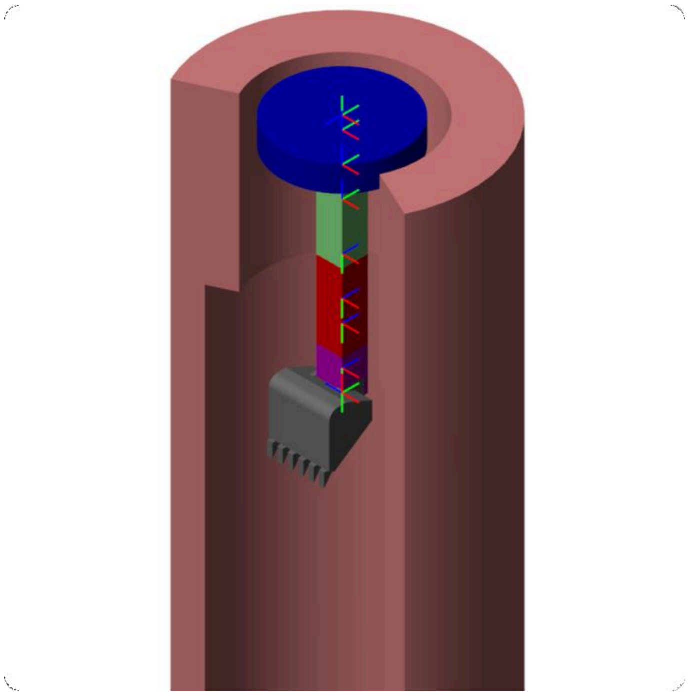


Figure 2.6 Movement of the arm

PID controllers, in conjunction with transformation and rotational matrices, enhance the arm's control. This allows us to pinpoint arm navigation at any desired positional coordinate. With the help of inverse kinematics, the arm will be able to determine and perform the required joint movements to extend to a target position, securing precision and responsiveness.

But the interchange between joints in the control system created a challenge, since rotating one joint caused hindrances in the other. To address this, a proportional-derivative (PD) controller was applied to one joint, while a proportional-integral-derivative (PID) controller managed the other. This configuration effectively minimized disturbances and ensured all system responses were stable and reliable. By working together with the kinematic matrices, the PID and PD controllers help the robotic arm move smoothly and accurately, allowing it to complete tasks effectively within the set limits.

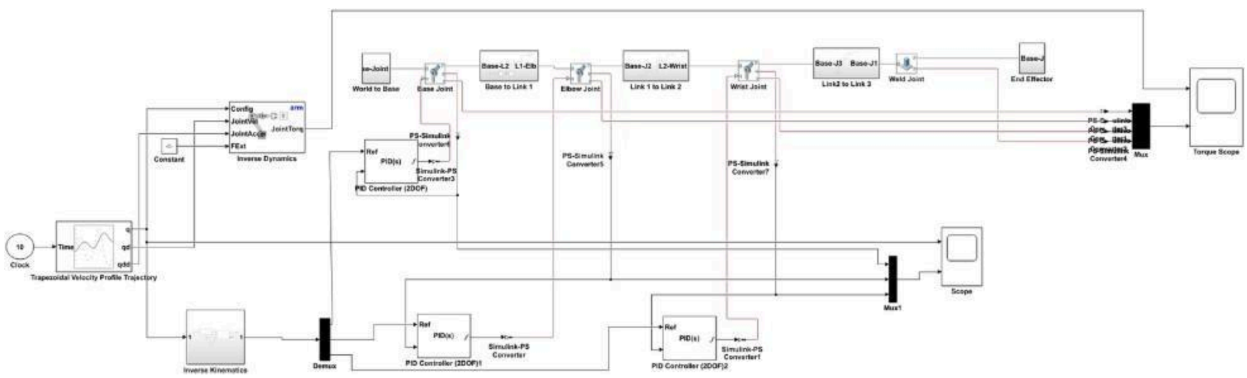


Figure 2.7 Simulink model for arm control using PID controllers

Figure 2.7 shows the Simulink model where inverse kinematics has been implemented for the rigid body tree of the 3 DOF arm. In inverse kinematics we give the coordinates that the arm needs to reach and it calculates the joint angles accordingly.

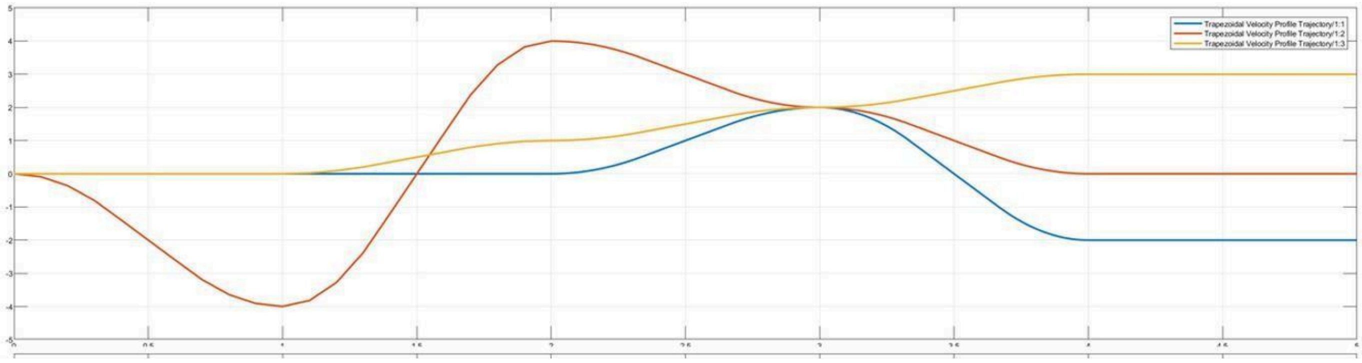


Figure 2.8 Response of arm model based on position response in inverse kinematics

Figure 2.8's graph clearly demonstrates our use of inverse kinematics. Our robotic arm successfully moved using the positional coordinates we provided. However, our simulation could not identify all the disturbances, so our input and output graphs look almost identical. We have tuned our PID to produce similar graphs, but in reality, there may be some discrepancies. But theoretically, the values used in our simulation are accurate.

2.4 Power Use Simulation and Calculation

2.4.1 Vacuum Pump Simulation

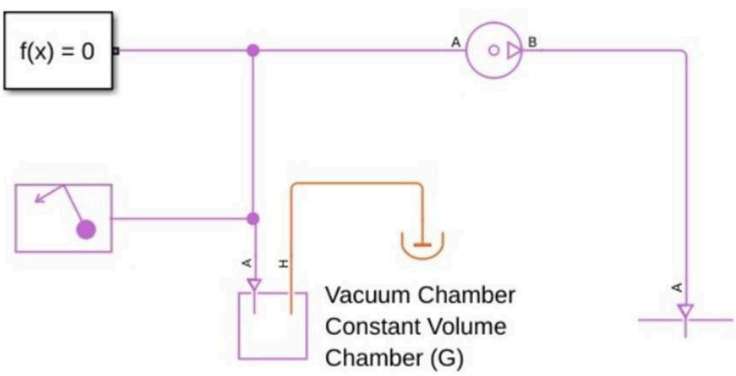


Figure 2.9 Simulation of vacuum pump in Simscape

Here, the vacuum chamber, modeled in figure 2.9 in Simulink, starts with atmospheric pressure; the reservoir represents the external atmosphere, and the pressure source models the vacuum pump, which removes gas from the chamber. The pressure source creates a pressure difference, causing gas to flow from the vacuum chamber to the reservoir, and as the gas is evacuated , the pressure in the vacuum chamber decreases. The solver configuration ensures that the pressure, temperature, and flow dynamics are updated in real time. Changes in gas flow are influenced by the properties of the vacuum chamber and the pump's capacity. Thereby, the vacuum pump achieves the desired low pressure in the chamber, and the reservoir absorbs the removed gas, maintaining the system balance.

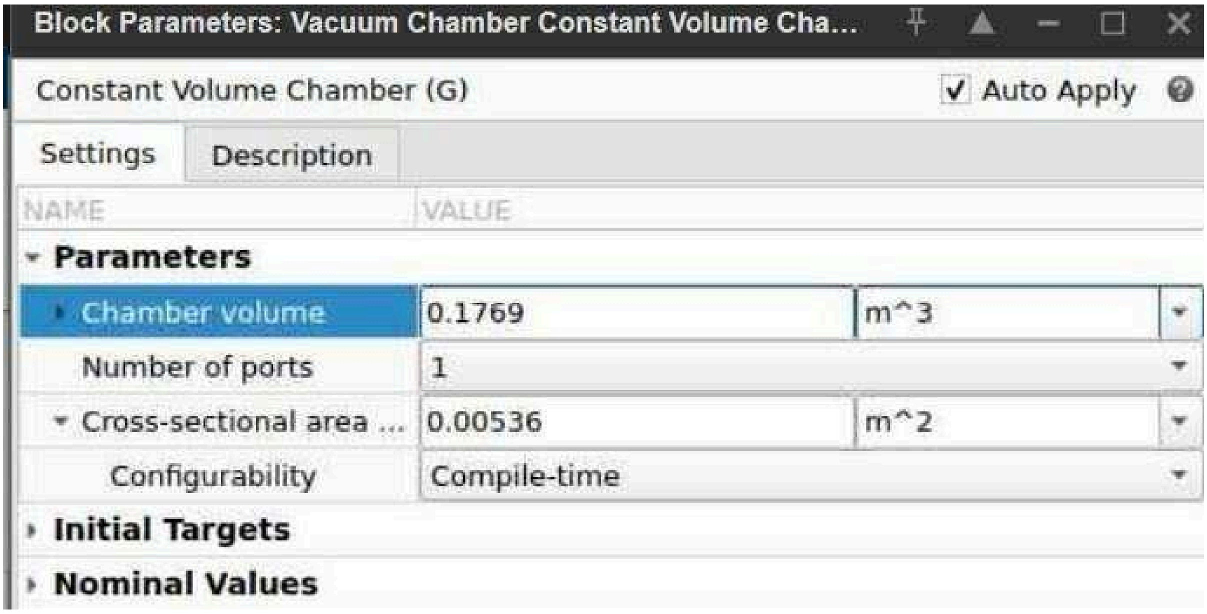


Figure 2.10 Parameter table for the vacuum chamber

We can also alter the dimensions of our vacuum chamber to suit our needs. Here, in figure 2.10, the cross-sectional area and the chamber volume are kept the same as the volume and area of the scoop (bucket) from our design approach 1. Furthermore, we can change the type of gas in the vacuum chamber by adjusting its density and viscosity in the pump design.

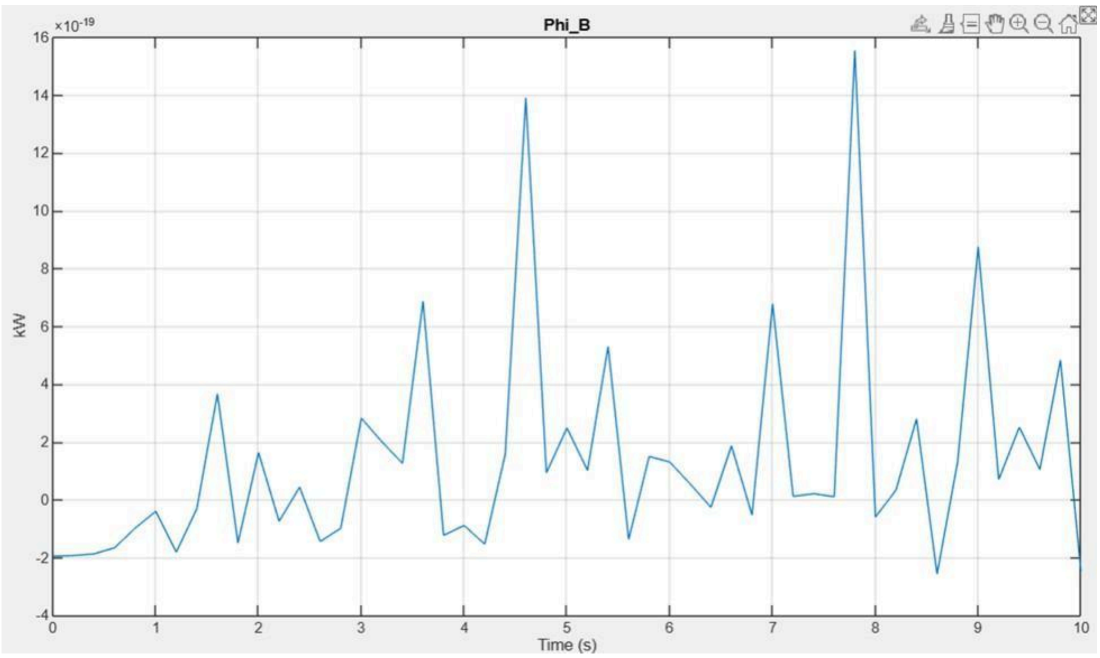


Figure 2.11 The output of power consumption from the vacuum chamber

The output of the simulation yields the figure 2.11, which displays intermittent spikes of different magnitudes, which is possibly due to the variable load experienced by the simulated pump, and more power would need to be consumed when the pump encounters an obstacle that is difficult to suction.

2.4.2 Power Calculation

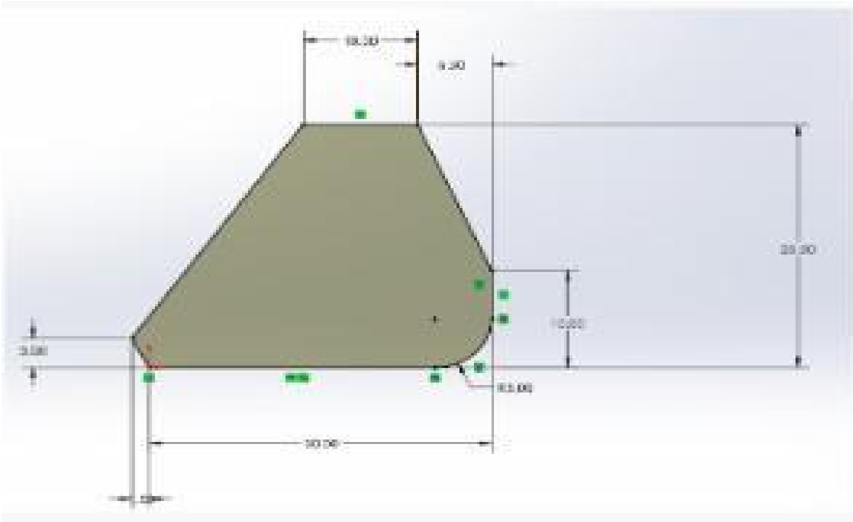


Figure 2.12 Measurement of the cross-sectional area of the bucket

Area Calculations:

1. Section (a):

$$Area = \frac{1}{2} \times (0.065 + 0.15) \times 0.15 = 4.875 \times 10^{-3}\, m^2$$

2. Section (b):

$$Area = (0.065 \times 0.1) + (\frac{1}{4}) \times \pi \times (0.05)^2 = 0.0652\, m^2$$

3. Section (c):

$$Area = 0.1 \times 0.25 = 0.025\, m^2$$

4. Section (d):

$$Area = [(1/2 \times 0.15 \times 0.25) - (1/2 \times 0.15 \times 0.09)] = 0.018525\, m^2$$

Total Volume:

$$Width\ of\ scoop = 0.33\ m$$

$$Volume = [(a) + (b) + (c) + (d)] \times Width$$

$$= (0.0536) \times 0.33 = 0.01769\ m^3$$

Volume of sludge in the pipe:

Assuming the sludge fills a height of 1 m in a pipe of 1.2 m diameter:

$$Volume\ of\ sludge = \pi \times (0.6)^2 \times 1 = 1.13\ m^3$$

Number of trips required to clear the blockage:

Bucket End Effector Design:

If one scoop can remove 0.01769 m^3:

$$Trips\ for\ bucket = 1.13\ /\ 0.01769 \approx 64$$

Vacuum End Effector Design:

Assuming the vacuum can store 0.1 m^3 of sludge per trip:

$$Trips\ for\ vacuum = 1.13\ /\ 0.1 \approx 11$$

From figure 2.12, the area of the bucket is found by assuming and breaking down the shape into different geometrical shapes: triangle, rectangle, and trapezium. In our design 1, the bucket's volume is found by multiplying the width by the height. We maintained the same volume and cross-sectional area for the vacuum pump chamber to facilitate easy comparison between the two models. Later, the number of trips to clean up the sludge required for both the bucket and the vacuum pump is shown above; the bucket needs 64 round trips, and the pump requires only 11 trips, but its power consumption is very high as we see while comparing table
2.1 and table 2.2.

Table 2.1 Power Budget for Design Approach 1

			Design Approach 1			
Components	Voltage(V)	Current(A)	Power(W)	Operating Voltage(V)	Operating Current(A)	Where used
Linear Actuators (x2)	12	1.5 each	36	12	1.5	Manipulator actuators
Linear Actuators (x6)	12	1.2 each	86.4	12	7.2	Locomotion actuators
Relay Module	5	0.2	1	5	0.2	Switching controls for actuators
MCU (Microcontroller)	5	0.3	1.5	5	0.3	Auduino
Raspberry Pi	5	2.5	12.5	5	2.5	control and comm
IP Camera	12	1	12	12	1	for sewer inspecc
Flashlight	12	0.5	6	12	0.5	visibility
Network Switch	5	0.5	2.5	5	0.5	IP camera and comm
		Total	157.9W			

Table 2.2 Power Budget for Design Approach 2

			Design Approach 2			
Components	Voltage(V)	Current(A)	Power(W)	Operating Voltage(V)	Operating Current(A)	Where used
Linear actuators(x6)	12	1.2 each	86.4	12	7.2	locomotion actuators
Pipe head of vaccum	24	2.5	60	24	2.5	part of the vaccum system
Vaccum pump	24	3	72	24	3	for suction of debris
Relay module	5	0.2	1	5	0.2	switching control for actuators
Microcontroler	5	0.3	1.5	5	0.3	arduino
Rasberry Pi	5	2.5	12.5	5	2.5	control and comm
IP Camera	12	1	12	12	1	for inspection vid
Flashlight	12	0.5	6	12	0.5	vision
Network switch	5	0.5	2.5	5	0.5	IP camera and comm
		Total	253.9W			

2.4.3 Communications Establishment Using Appropriate Protocol

2.4.3.1 Cisco Packet Tracer

Cisco Packet Tracer is a network simulation tool used for designing various network topologies and visualizing how each Protocol Data Unit (PDU) in a network is shared or transmitted. With its many distinct features, you can simulate a wide range of scenarios depending on the parameters you set and the mode you select. It also offers both logical and physical mode displays that allow hardware connections and modifications to be made if required.

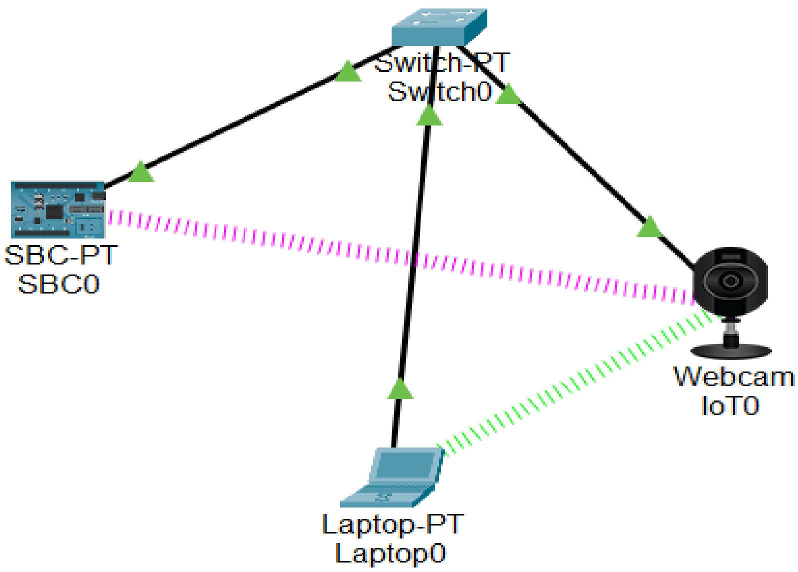


Figure 2.13 Logical Layer Representation of the LAN Network

In order to simulate the Local Area Network (LAN) setup required for the robotic arm to function, the topology that suits the system has been depicted in figure 2.13. A switch has been introduced to act as an intermediary between all the main nodes of communication in the system. In the logical layer representation below, it is demonstrated that all the channels between the switch and the nodes are active (indicated by the green arrows). The webcam represents the low-light camera used for vision assistance by the human operators as the robot is descending down the sewer, which requires a high rate of video feed transmission from the camera to the base station (represented by the laptop), so a wired connection, preferably ethernet, is used. The dashed lines represent wireless connections, such as Bluetooth, which is possible (as demonstrated here) between the components but not recommended due to the distance and barriers encountered by the system as it moves underground. The Single Board Computer (SBC) represents the microprocessor to be used on-board the robotic system, and, as shown, it is also connected via Ethernet to the switch, which relays the data to and from the base station.

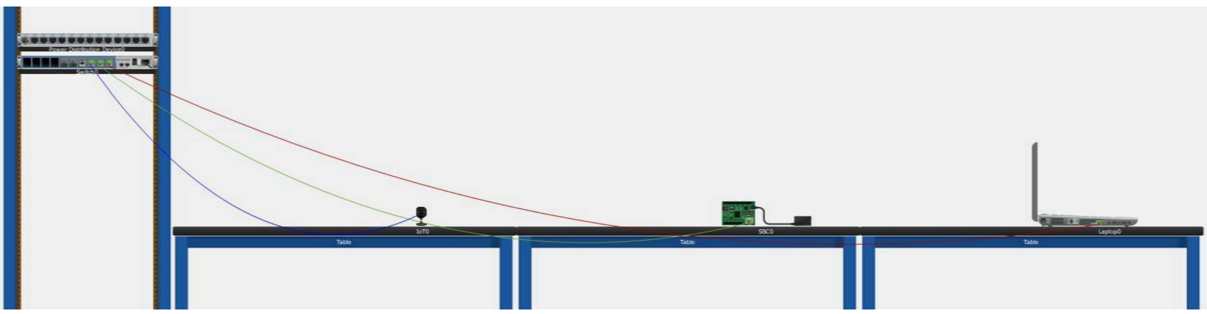


Figure 2.14 Physical Layer Representation of the LAN Network

In the physical layer (refer to figure 2.14), the visible wired connections are present, on the other hand. Both layers allow the user to access the features of the devices via GUI such as displayed below.

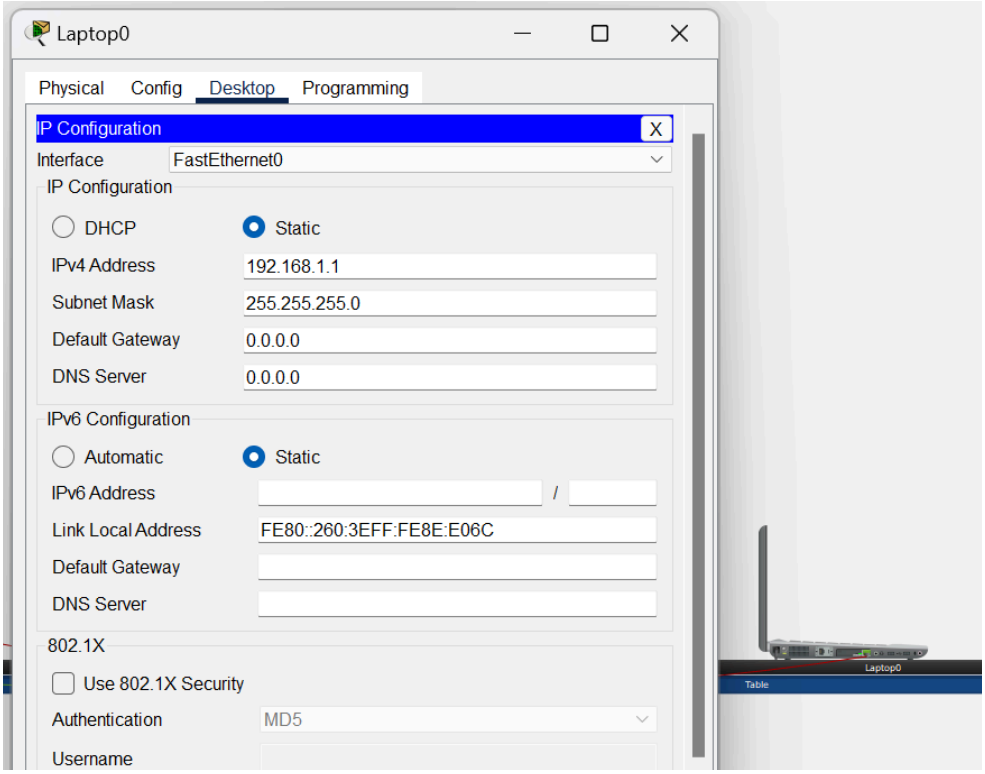


Figure 2.15 Assigning Static IP to Base Station

Since all devices are connected in a LAN, each device has been assigned a different static IP address with the same subnet mask so that they can communicate with each other. Desktop features, such as IP configuration, are accessible via the GUI of the laptop in Packet Tracer. A static IP has been assigned to the laptop as shown in figure 2.15

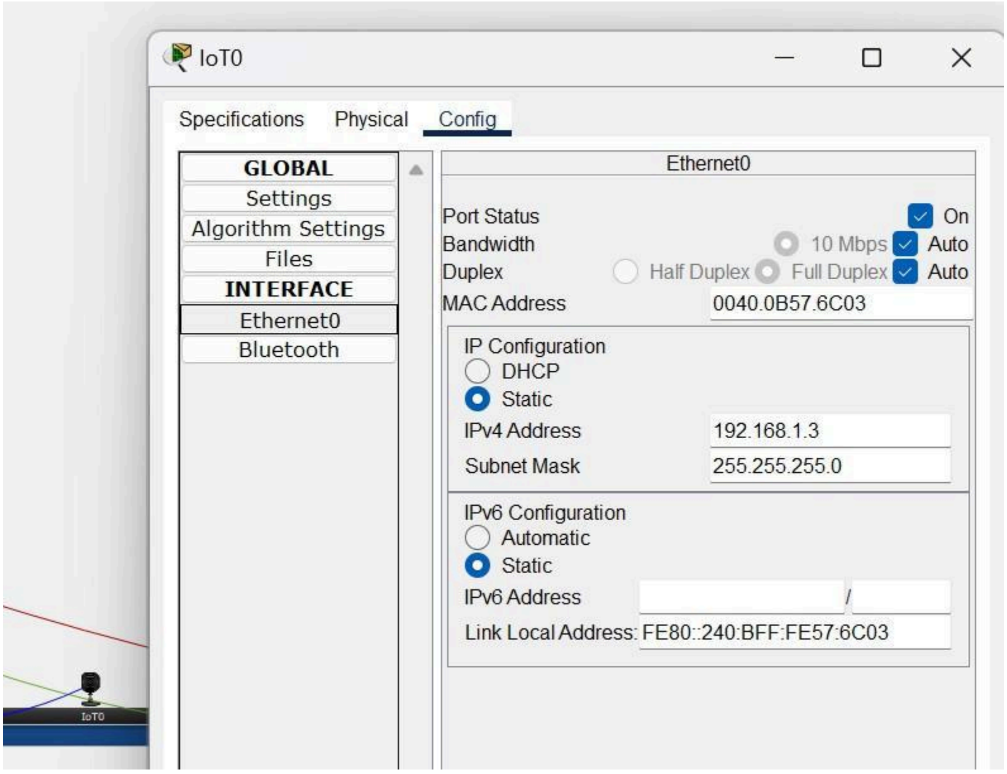


Figure 2.16 IP Address Configured for the Webcam

As shown in figure 2.16 other network devices, like the webcam, will also get static IPs. Whether or not a successful connection has been established can be determined by going to the command prompt of any device and trying to ping any of the other devices.

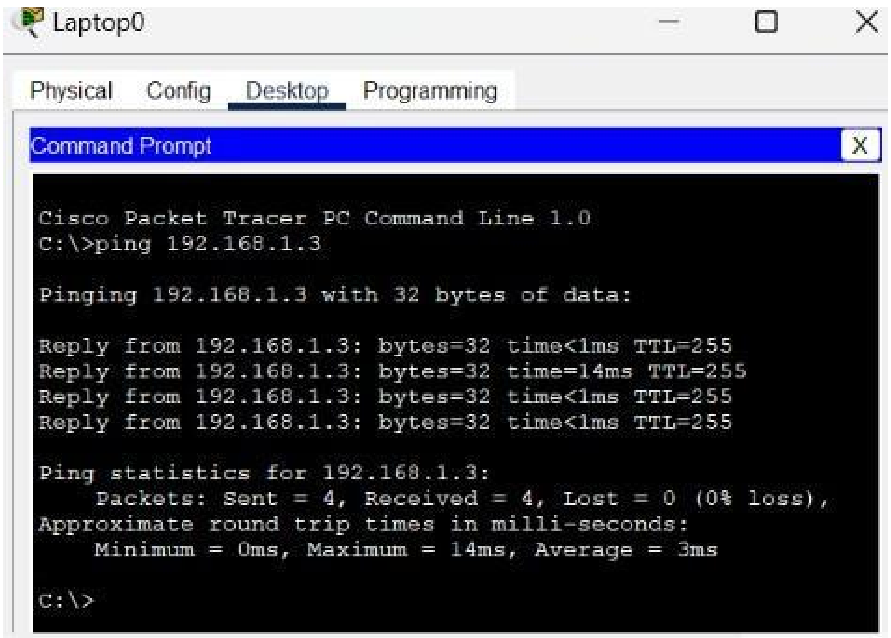


Figure 2.17 Demonstration of Successful Connection using Command Prompt Pings

Once the IPs have been assigned to each device, the laptop can send and receive packets from the webcam, and vice versa. Using the command line interface of the laptop, the webcam has been pinged (sent packets and waits to see if the packets has been received and acknowledged), and successful communication within the LAN has been established since we see that the webcam replies via packets of its own, evidenced by Figure 2.17 above.

2.4.3.2 MATLAB Simulink

From the Vehicle Network Toolbox Library in MATLAB Simulink, the CAN pack and unpack blocks have been acquired along with the CAN transmit and receive blocks. The CAN configuration blocks are used to define which messages are dedicated for each channel.

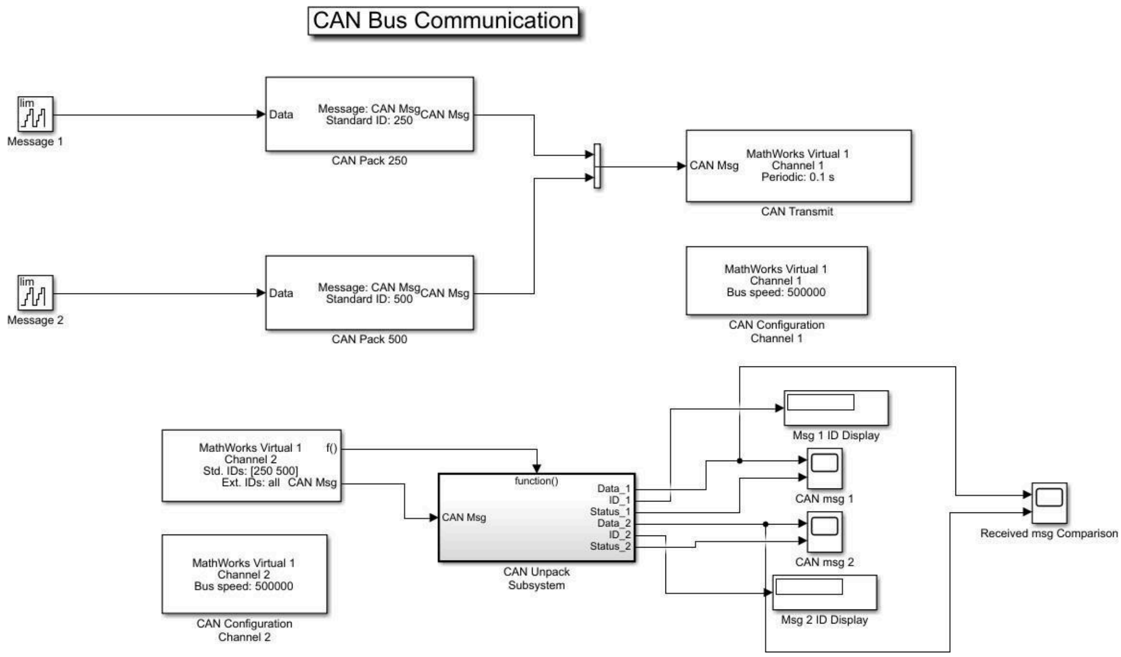


Figure 2.18 Simulink Model for CAN Communication

Figure 2.18 shows two separate messages with ID 250 and 500 respectively are packed into CAN frames (with appropriate headers, CAN ID, error detection and correction codes etc.) which are then multiplexed into one single data stream and transmitted to all nodes. Only the node with the prescribed ID matching the transmitted message's ID will unpack the data stream and display the message separately.

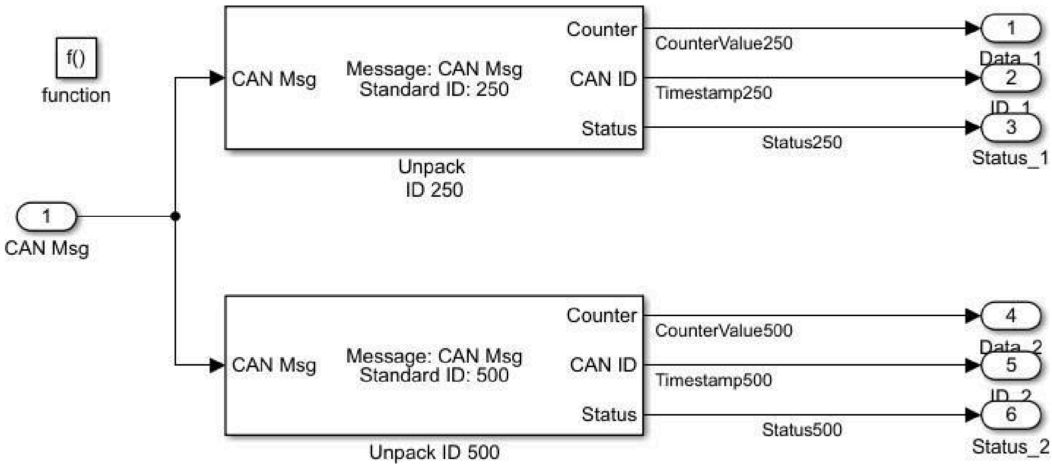


Figure 2.19 The CAN Unpack Subsystem

The message unpacking subsystem from figure 2.19 consists of CAN Unpack blocks, which receive the multiplexed message from the central medium and demultiplex it into two separate signals, which will be sent to be displayed in the scopes for visual representation.

Simulation output:

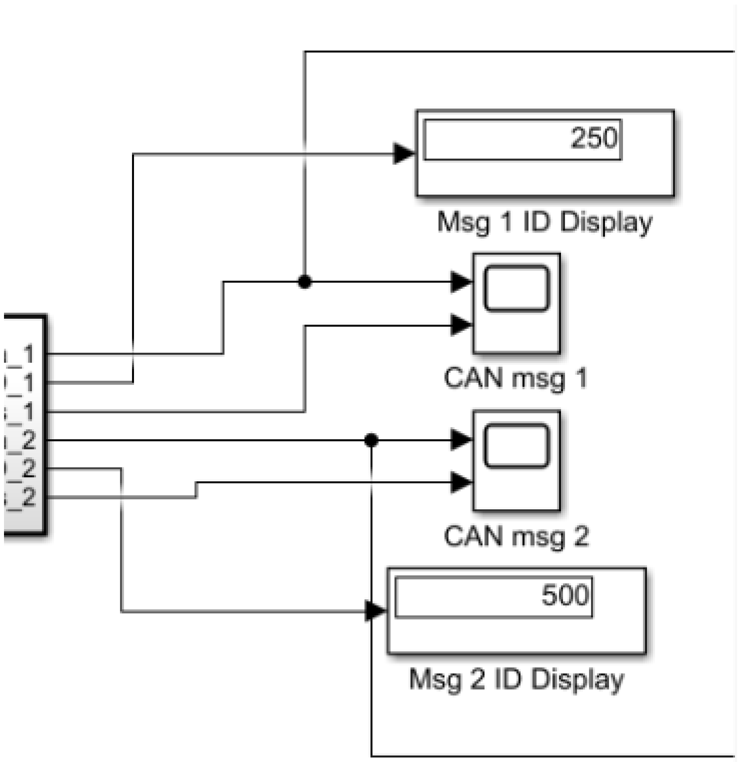


Figure 2.20 CAN Unpack detects individual message based on their assigned ID

The results in the display in figure 2.20 show that the messages has been received, decoded and identified based on their IDs even though they shared the same medium and the same encoding format, which indicated that the CAN Bus can be used to exchange messages via one central cable connecting the SBC and the base station in this system.

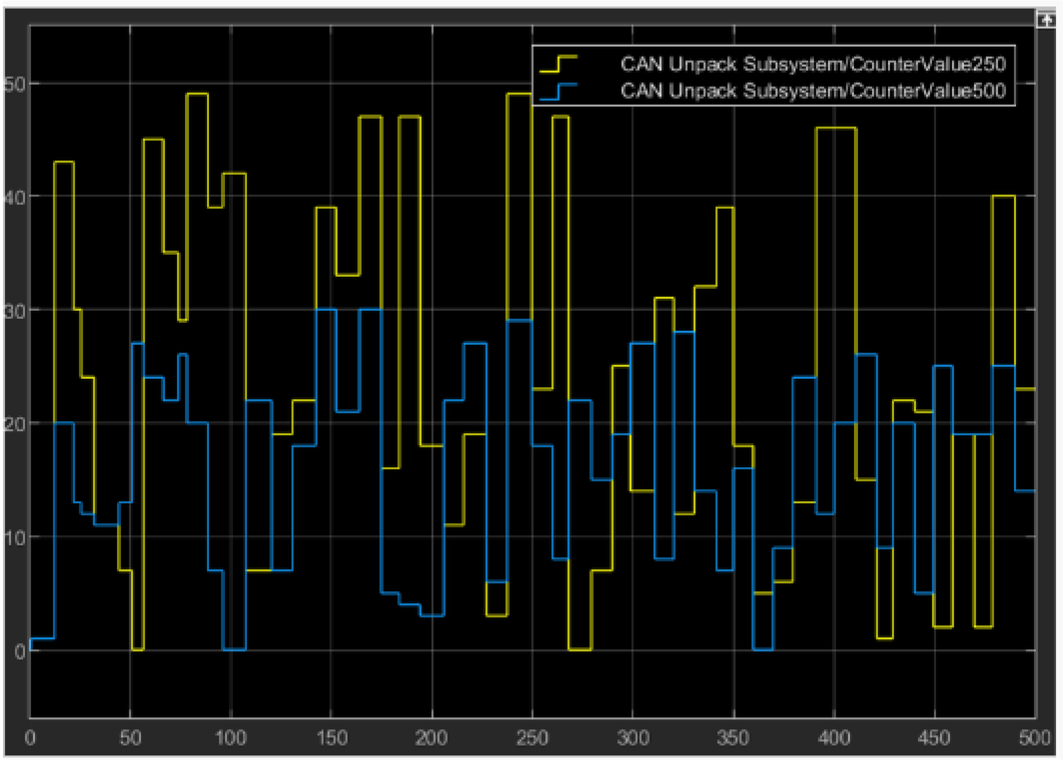


Figure 2.21 Messages decoded and displayed separately

The output received from the simulation (figure 2.21) assures that the CAN Bus communication has been successfully established because it is clear from the scope output that the two messages which have shared the same medium for communication have not interfered with each other and the outputs can be distinctly identified. Thus, it proves that CAN Bus can be used to send commands from base station to individual MCUs, actuators and sensors and receive their readings using one central Ethernet cable.

2.4.3.3 Proteus Simulation

To simulate CAN Bus Communication using Proteus software, the PIC18F884 microcontrollers, which have in-built features for CAN communication, has been used and constructing a sub-circuit for MCP2551 (since it is not available as an IC in the Proteus Library), which is a Controller Area Network (CAN) board designed to be used with PIC MCU boards for interfacing purposes.

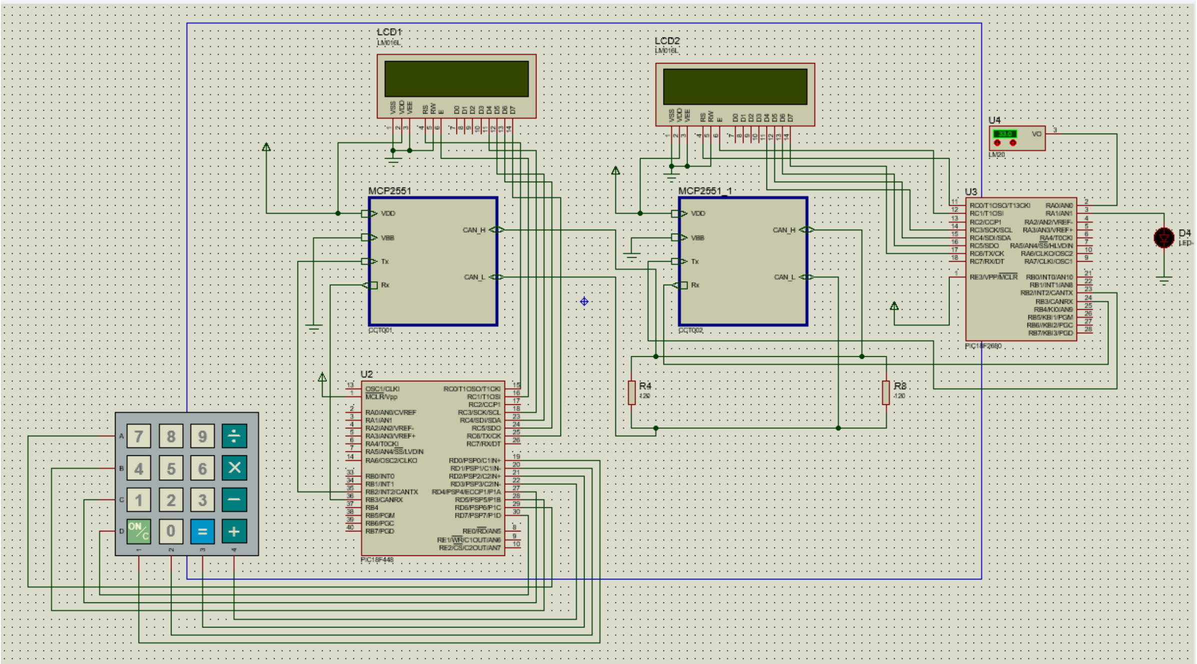


Figure 2.22 Proteus Circuit of Simulated CAN Communication

In figure 2.22, a CAN Bus channel has been included with 120-ohm resistors at each end, as directed by the CAN Bus Protocol. Two C programs have been written to transmit the temperature sensor data when the button ‘1’ has been pressed on the keyboard, and the LED is controlled with key ‘2’ as well as the LED’s status, which is displayed when the LED turns on, mimicking a warning light and message.

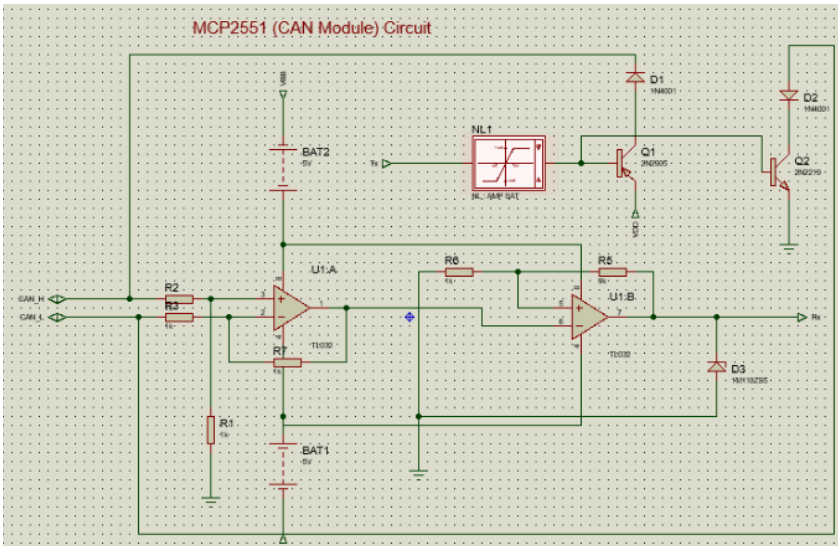


Figure 2.23 Sub-circuit for MCP2551

The sub-circuit shown in figure 2.23 has been designed following the datasheet of MCP2551 provided by the manufacturer.

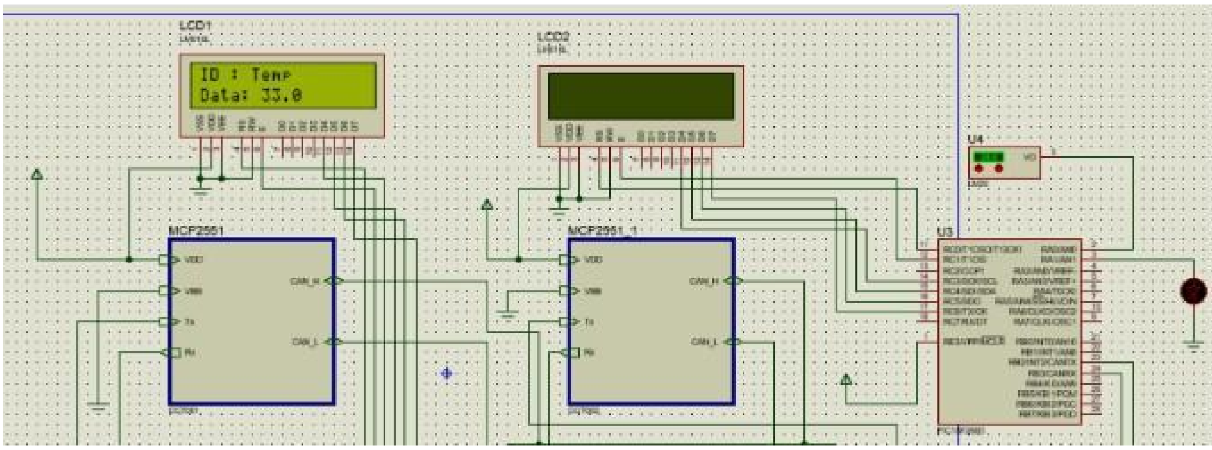


Figure 2.24 Display output when 1 is pressed on the keyboard

Figure 2.24 shows the output when the simulation is run and the keyboard is used to send a numerical '1' as the message to the MCUs which has been programmed to show the temperature sensor data for this command and it then activates the CAN board and retrieves the temperature data from the sensor, finally displaying it on the LCD.

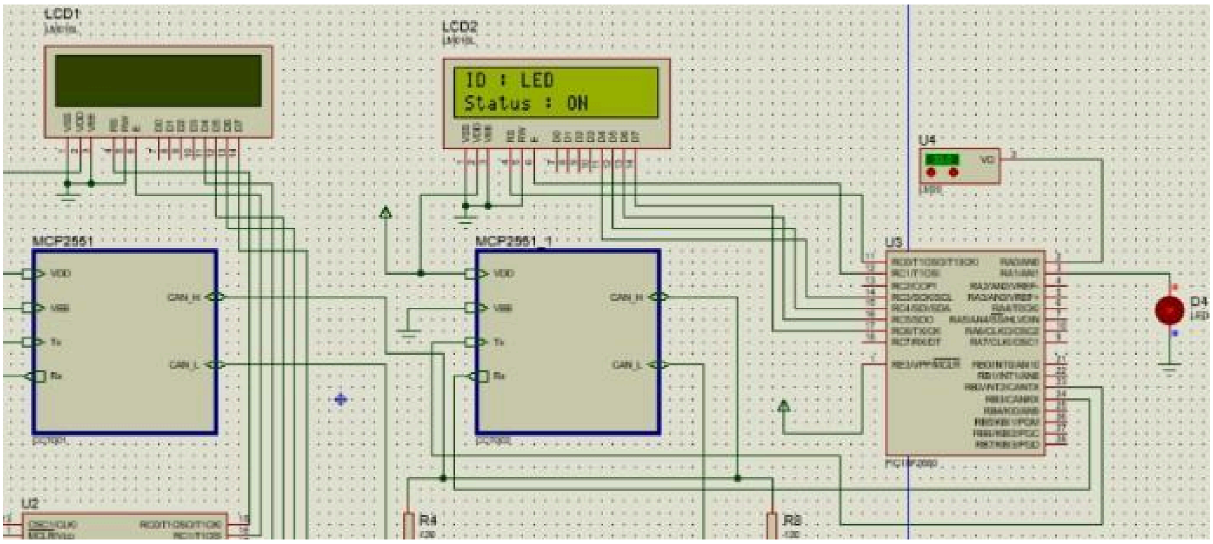


Figure 2.25 Display output when 2 is pressed on the keyboard

Figure 2.25 illustrates the result of pressing '2' on the keyboard, which has been programmed as the command to turn the LED on. The LCD now displays the status of the LED. This action demonstrates that the CAN boards not only retrieves data but can also send commands to the peripheral components if required.

2.5 Conclusion

From the simulations above as well as the literature review and field study, it has been concluded that Design Approach 1 (robotic arm with end effector as a bucket) would be more power efficient, cost-effective, safe, and easier to set up and use than the alternative design approach consisting of the vacuum pump. As such, design 1 will be implemented in hardware in the next and final phase of Final Year Design Project, namely the Completion phase.

Chapter 3: Use of Modern Engineering and IT Tools. [CO9]

3.1 Introduction

Numerous modern engineering and IT tools have been employed to design, simulate and develop the robotic arm as well as to perform the comparison between the two suggested approaches in an attempt to determine the most optimal design. The selection and method of implementation of the tools are outlined below.

3.2 Selection of Appropriate Engineering and IT tools

TABLE 3.1: SELECTION OF MODERN ENGINEERING TOOLS

Sub-system	Engineering tool/software used	
	Engineering tool	***Why this tool was chosen***
Structure	Fusion 360	AutoCAD Fusion 360 offers a wide variety of features tailored for custom 3D Design with user friendly and intuitive interface and parametric modeling for setting accurate dimensions of the objects.
Kinematics and PID control	Matlab Simulink	Matlab Simulink offers a wide range of tools for designing and simulating robotic arms such as kinematics, inverse kinematics, dynamics etc. It also allows integration with solidworks for complete visualization of the arm's joints and links.
Power usage simulation	Matlab Simscape	Matlab Simscape consists of all the mathematical blocks to design our vacuum pump model, all the parameters can be altered to our choice and it gives the output waveforms of power usage and mass flow rate.
Communication Protocol (Topology setup)	Cisco Packet Tracer	This software is suitable for logical and physical layer representation of communication topologies as well as allowing various system and PDU conFigureurations to allow for better comparison and selection of communication protocols
Communication Protocol (CAN Bus Simulation)	Matlab Simulink Proteus Professional	Matlab Simulink consists of ready library blocks for CAN Bus packing and unpacking that helps simulate the required scenarios and provides helpful visualizations. Proteus Professional provides an intuitive virtual environment where MCUs and their in-built features (in this

		case, CAN Tx and Rx) can be used to simulate tasks as required and the availability of peripheral components such as LEDs and Sensors help demonstrate the output of the protocol used.
Mechanical Controls	ROS Robotics Operating System	Robot Operating System (ROS) has been used as framework to effectively communicate between the base station and the on robot computer. With the help of ROS from the base station we send commands to the ROS core and ROS core handled communication to each nodes for communication, telemetry etc.

Chapter 4: Optimization of Multiple Design and Finding the Optimal Solution. [CO7]

4.1 Introduction

With regards to optimization and comparison, there are two categories upon which the analysis can be based. Given that the robotic arm and its joints are constant features in both the approaches, the factors upon which the optimal design can be chosen are the payload capabilities and the power consumption specifications of the approaches. We will also contrast other qualitative features, which are equally important to consider, to determine the optimal design approach.

4.2 Optimization of Multiple Design Approach

Having mentioned in the specifications that payload capacity is an essential element when designing an unclogging mechanism for sewers, a clear and straightforward calculation has been carried out in Chapter 2 Section 4 to determine which approach would be more suitable in this category, which showed that the vacuum pump and bucket would require 11 and 64 round trips respectively to clear 1 m^3 of waste and sludge from the sewer.

The calculations thus dictate that the Vacuum approach would be much quicker since it has a larger capacity for storing the sludge for removal. However, there are multiple other factors that should be considered when deciding which method would be more efficient, cost-effective and sustainable. Thus, another category to be assessed is the amount of power each approach would require to carry out its purpose.

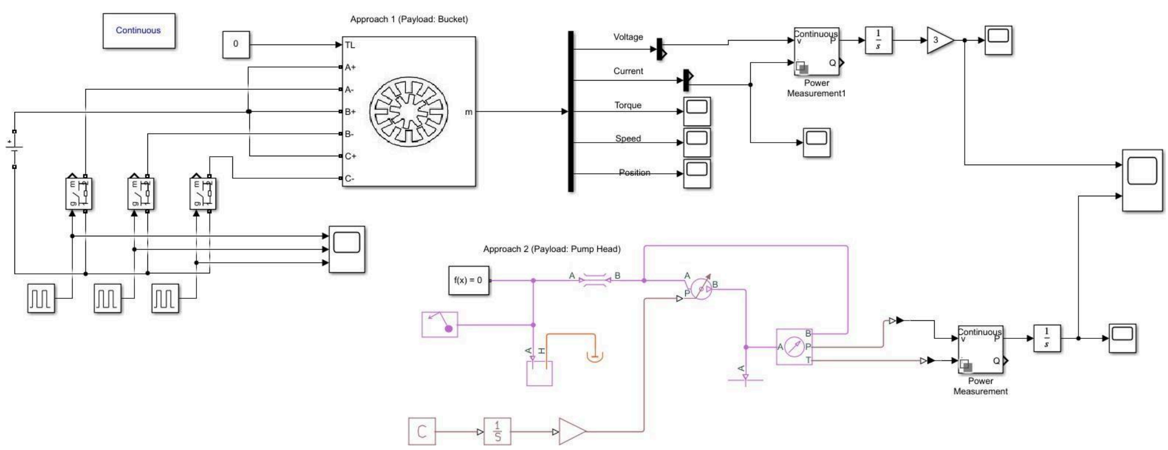


Figure 4.1 Simulink Model for Power Consumption Comparison

Figure 4.1 shows a simulink model has been constructed for this particular power consumption assessment using appropriate blocks to model the motors and the vacuum pump.

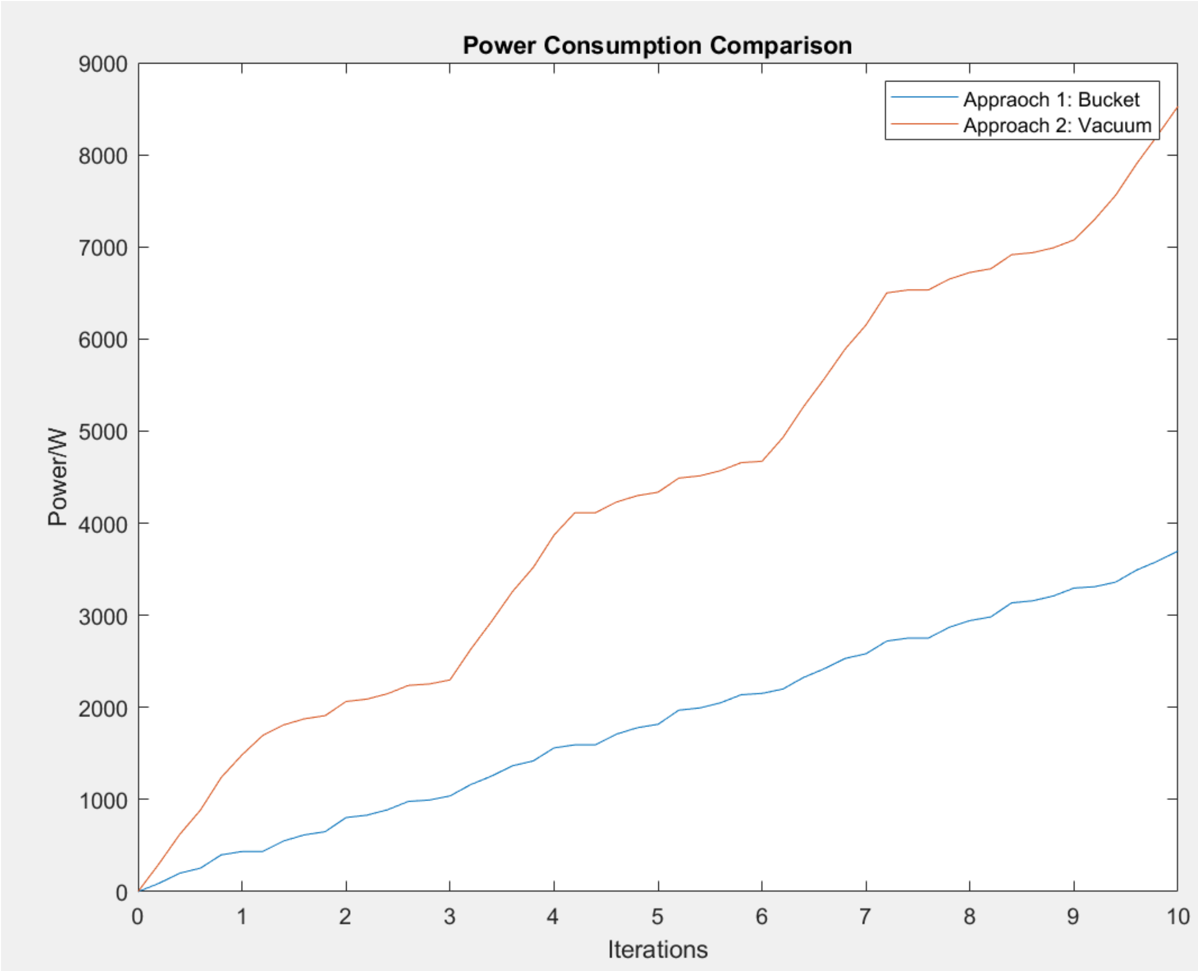


Figure 4.2 Output of the Power Consumption Comparison Model

It is observed from the output illustrated in figure 4.2 that every time the pump is activated to pull out the waste and clear that section of the sewer, there is a huge surge in power consumption and the wattage climbs steeply. Although less iterations of vacuum trips are required when compared to the bucket approach, the amount of power required as a supply to complete 11 activations of the vacuum pump is immensely larger than the power that would otherwise be consumed by choosing the bucket as the end-effector. Furthermore, since the vacuum pump needs to be of the industrial sub-type, an additional generator would be needed to operate the pump which adds to the complexity, cost and difficulty of mobility of the pump approach, all of which will be looked down upon negatively according to our objectives and requirements.

Nevertheless, there are other qualities and factors that are also worth considering when making the comparison and arriving at the optimal solution. All such factors, as well as the two described above, are summarized in the table below.

TABLE 4.1: COMPARISON BETWEEN THE TWO APPROACHES

Factor/Category	Comparison	
	Approach 1 ***(Vacuum Pump)***	***Approach 2*** ***(Bucket/Scoop)***
Payload Capacity per trip	0.1 m^3 (capacity of the collection compartment)	0.018 m^3 (volume of the bucket)
Power Consumption per trip	~2200 W	~1000W
Type of Payload	Only able to collect liquid or semi-liquid waste. Solids of radius bigger than the pump opening will not be retrieved, might even block the opening and disrupt operation.	Able to collect liquid, semi-liquid and solid wastes which is essential for the unblocking objective.
Mobility of system	Difficult to carry and/or transport. Very bulky, much heavier, and requires an external generator.	Much easier to carry or move the entire system from one place to another.
Cost	Projected at almost Tk. 1.48lacs (due to external generator and industrial vacuum costs), it would be an extremely expensive system.	Projected at Tk. 73,000, it is much more feasible and affordable, which will in turn keep the market price relatively lower as well.
Maintenance	Clearing the waste collection chamber after every trip might prove to be troublesome and the maintenance cost of the vacuum would be significant in the event of any technical issues.	Waste disposal and overall system maintenance is much simpler, cheaper and less time- consuming.

4.3 Identify Optimal Design Approach

Therefore, considering all these factors and categories, it is evident that Approach 2 (Bucket/Scoop) would be more preferable as not only does it meet all the objectives and requirements, but it does so while consuming less power, being more affordable and more usable as well as durable. Thus, Approach 2 will be chosen as the optimal solution to address the problem at hand and it will be developed and implemented physically, after which its performance will be evaluated and assessed to discuss possible future improvements and modifications.

4.4 Performance Evaluation of Developed Solution

The chosen solution to be developed, robotic arm with an end-effector as a bucket or scoop, has been modelled in Simulink, which allows ease of design for many such complex robotic systems through the Robotics Toolbox, to demonstrate its functionality and performance. The PID controlled output of each joint or link has been graphed along with the applied angles for the motors to check the accuracy of this simulated project.

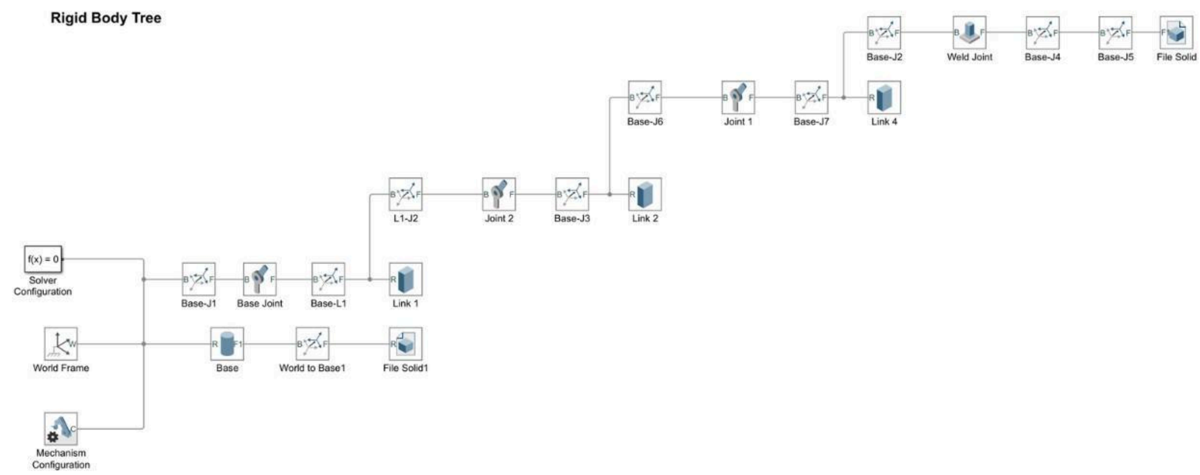


Figure 4.3 Rigid Body Tree of 3 DOF Arm

In figure 4.3, we modelled the 3-degree-of-freedom arm using a rigid body tree. Here the joints have been specified according to their type and each body has been configured based on material and density.

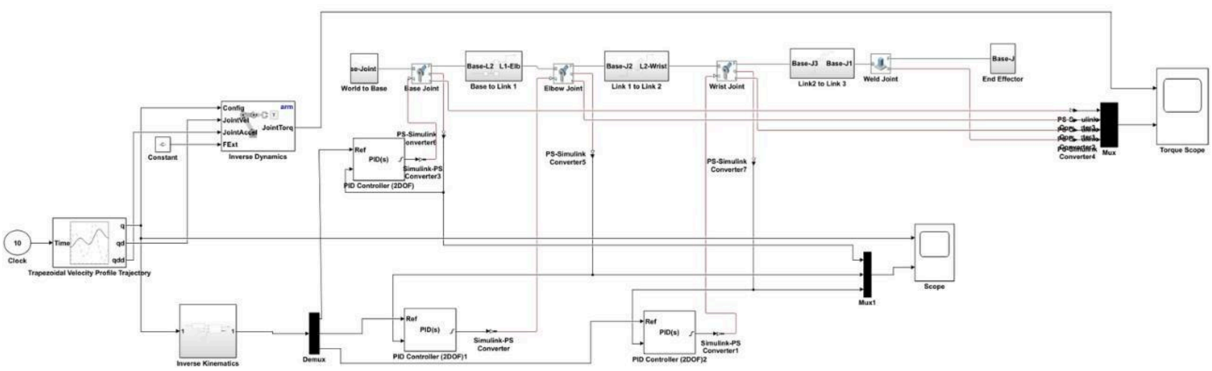


Figure 4.4 Forward Kinematics of 3DOF Arm

In figure 4.4, we implement forward kinematics on the above-mentioned rigid body tree model. Here, each joint is moved in specific angular directions.

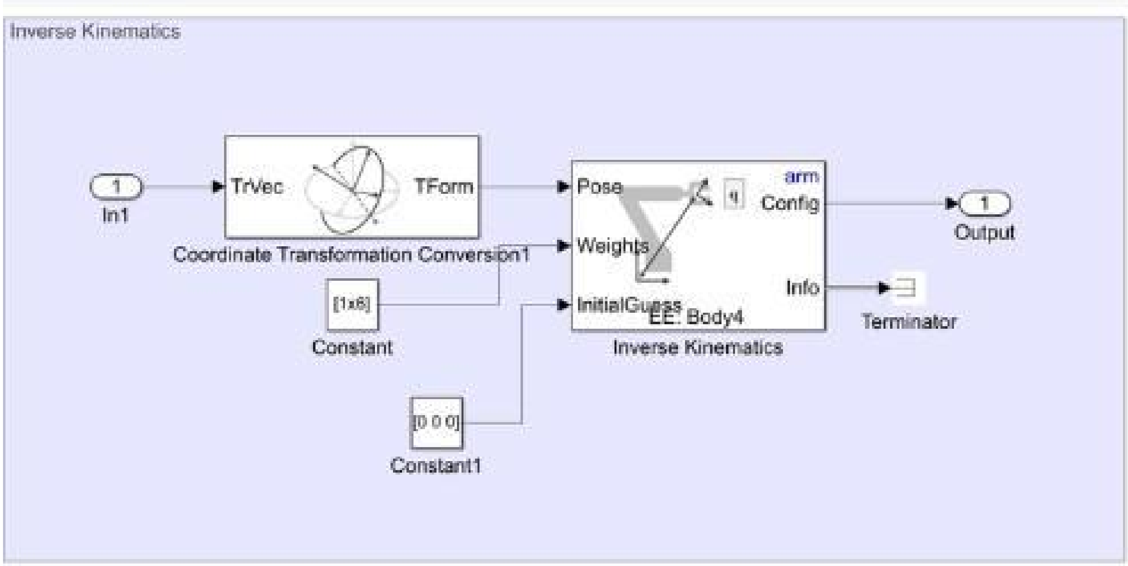


Figure 4.5 Inverse Kinematics Block of 3 DOF Arm

Figure 4.5 shows the inverse kinematics block used on the rigid body tree. In inverse kinematics, coordinates are converted to angular directions. Here, the built-in Simulink block is shown.

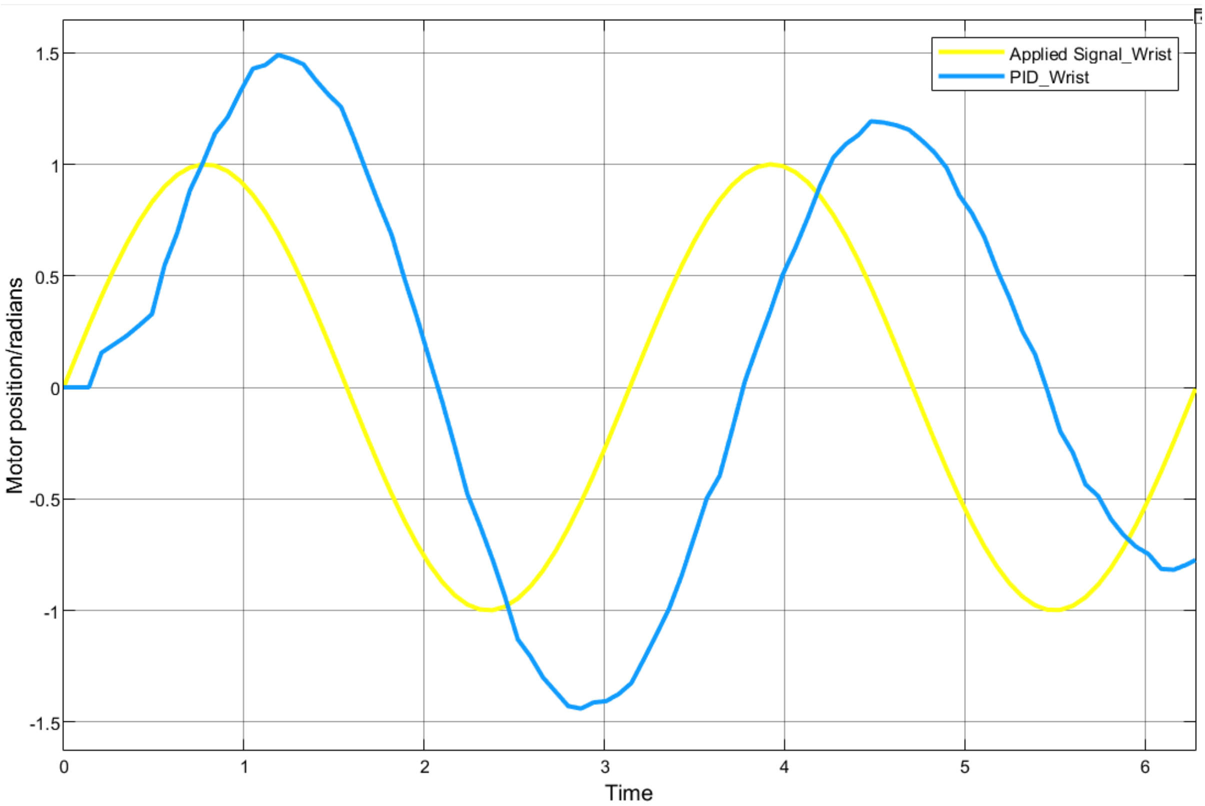


Figure 4.6 PID Output of Wrist Joint

Figure 4.6 shows the PID controlled output of the Joint attached to the end-affector, which was termed as the Wrist joint. The output shows that the PID response of the simulation is not following very closely with the applied movement, nevertheless the response is partially similar.

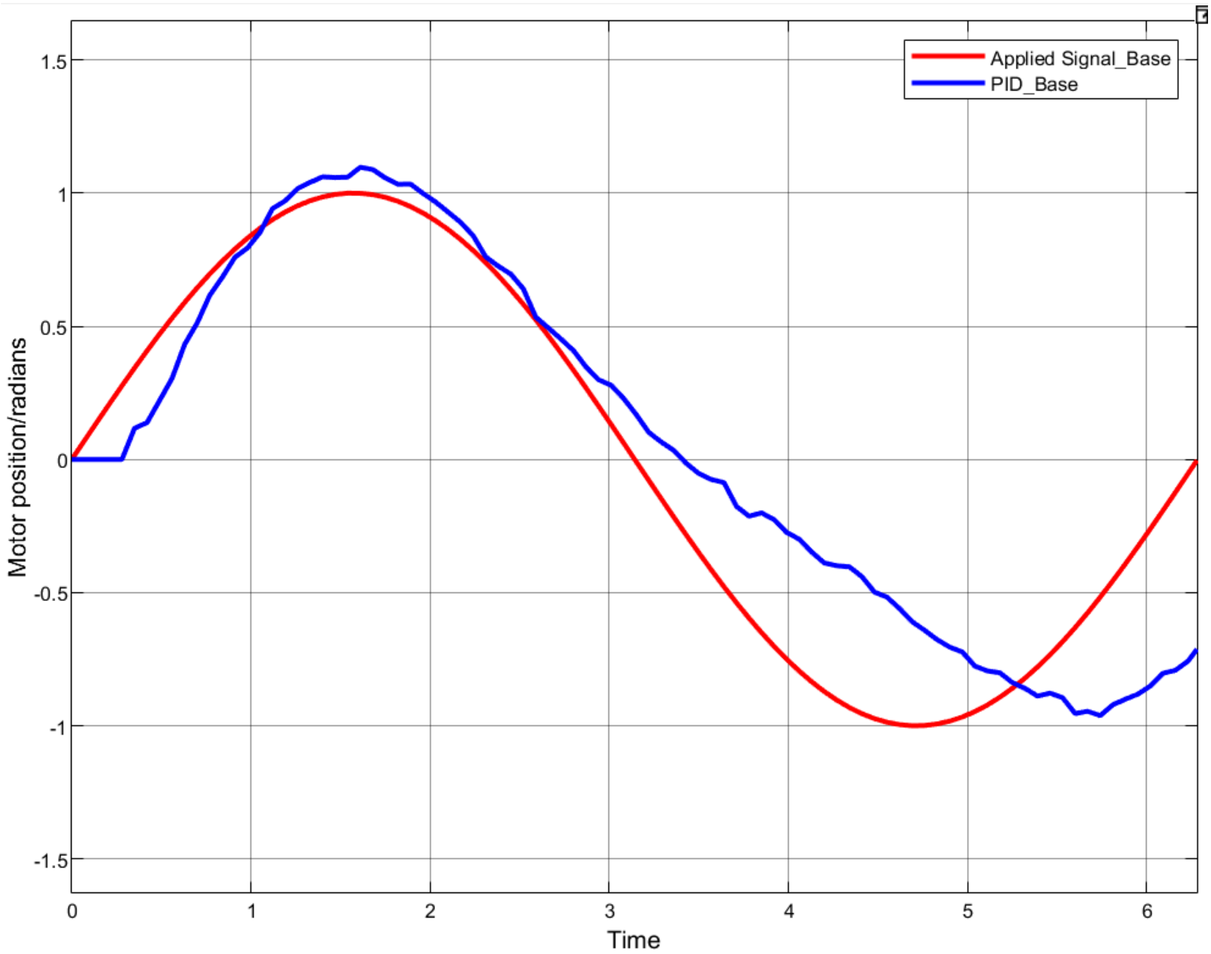


Figure 4.7 PID Output of Base Joint

Figure 4.7 shows the PID-controlled output of the motor attached to the base, which was termed as the base joint. The output, similar to the wrist joint, shows that the PID response of the simulation is somewhat similar to the applied signal.

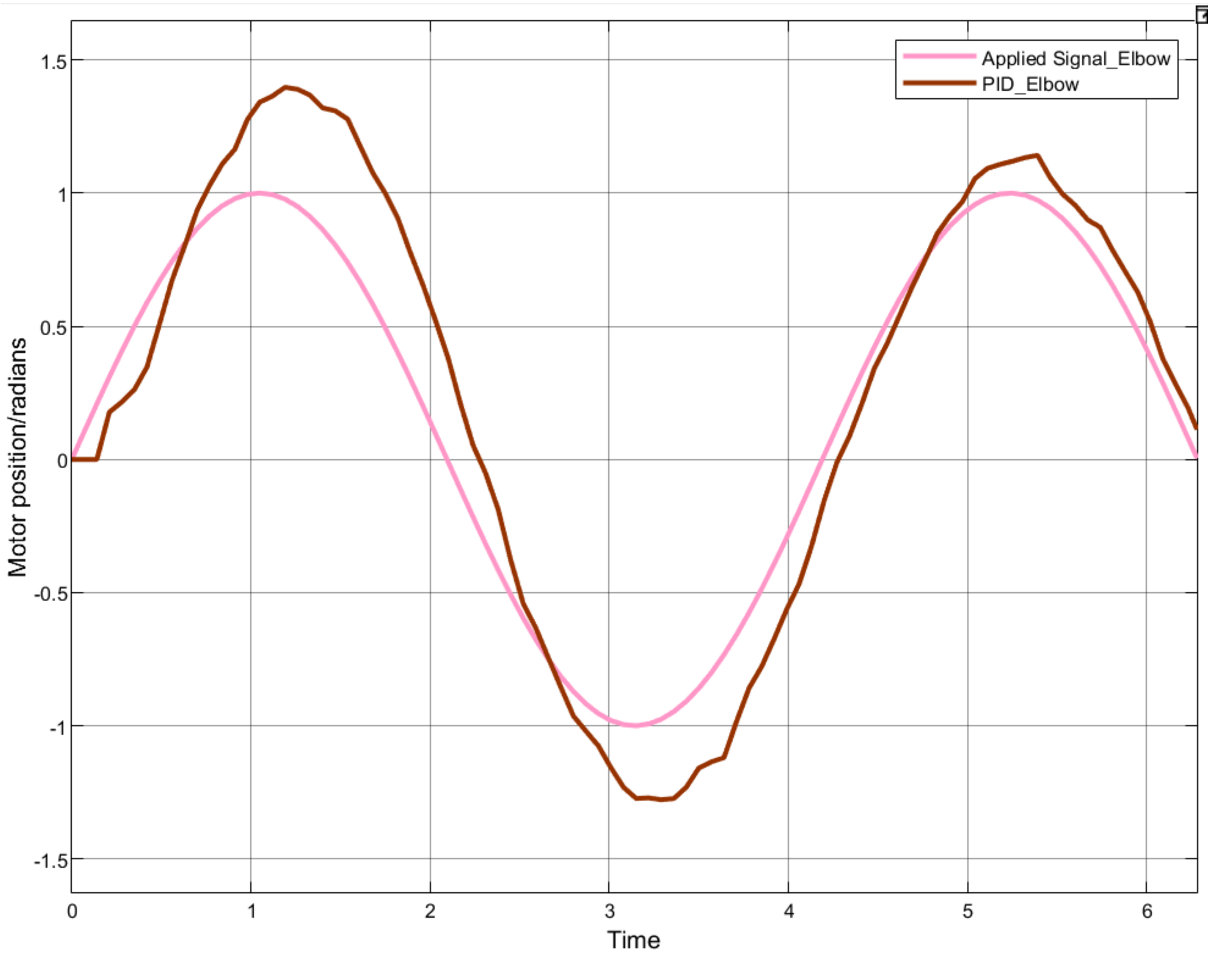


Figure 4.8 PID Output of Elbow Joint

Finally, figure 4.8 shows the PID-controlled output of the motor attached in the middle of the two pipes, which we termed as the elbow joint. The output, similar to the other outputs, shows that the PID response of the simulation follows the applied signal to an acceptable degree.

It must be noted that although there are some discrepancies and delays in the response, after tuning via trial and error method, the PID control appears to be working well since it follows the applied input parameters closely. Hence, the hardware-implemented system will be tuned with the same values to obtain and assess the PID response of the robotic arm system.

4.5 Conclusion

Upon comparison and analysis of the qualitative as well as qualitative factors relevant to achieving the outlined objectives of the system, it has been determined, through calculations, theoretical considerations and software-aided simulation, that Approach 2, which entails attaching a bucket to perform the scoop and excavate operation, would be more suitable for our purposes and optimal among the two approaches discussed. The next chapter will include and involve details regarding the hardware implementation and subsequent performance of the developed system.

Chapter 5: Completion of Final Design and Validation. [CO8]

5.1 Introduction

Following the selection of Approach 2 consisting of the bucket to be the most optimal solution among the ones assessed, it has been implemented in hardware following the outline of the system modelled in Simulink. Moreover, other features such as the functional and non-functional requirements have also been implemented in full, such as the visual subsystem for monitoring and control and the LAN conFigureuration for wired and wireless communications. The complete description of the system is presented below, along with pictures of the finished project.

5.2 Completion of Final Design

As per the specifications and proposed design, the robotic arm would have three joints—base, elbow, and wrist—that fulfill the technical requirements for being able to maneuver and extract waste from any section within a sewer system. The base joint will rotate 360 degrees to be able to access any point within the circumference of the manhole or sewer, the elbow joint will bend in order to move the bucket closer to the clogged area, and the wrist joint will move the bucket or scoop up and down so that waste can be collected onto the bucket. The robot will then be pulled out of the manhole via chains attached to the base vertically to act as a pulley.

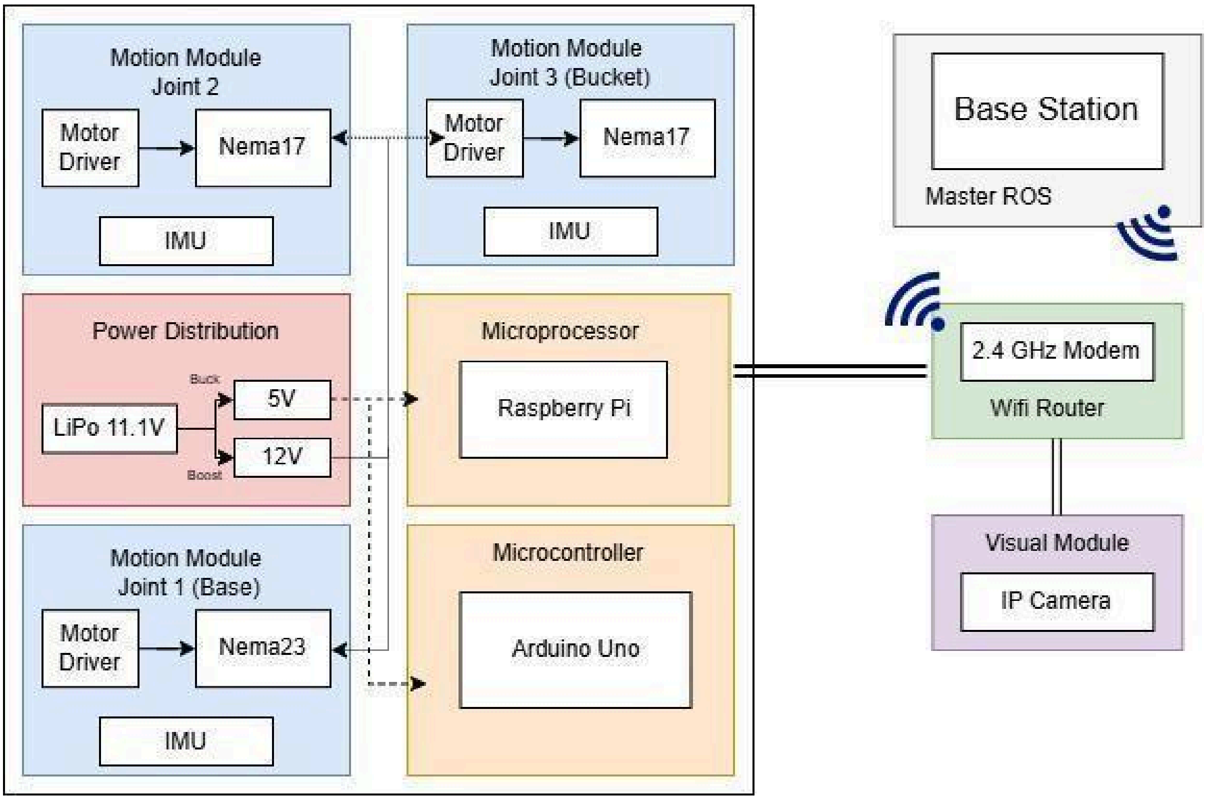


Figure 5.1 Block Diagram of Developed System

The robot will have five subsystems—communication, control, motion, vision, and power. The block diagram in figure 5.1, which outlines the subsystems and their connections, is attached

below. The base station, from which the operator will view the video feed and relay the commands for movement of the robot, will be connected to the LAN wirelessly, whereas the micro-processing unit and the camera will be connected to a router via Ethernet cables and assigned static IP addresses since the distance and the layers of concrete will not allow signals to propagate sufficiently for communication. The base station will subsequently connect to the local area network via the router and leverage SSH protocol to send commands to the microprocessor and thus the microcontrollers.

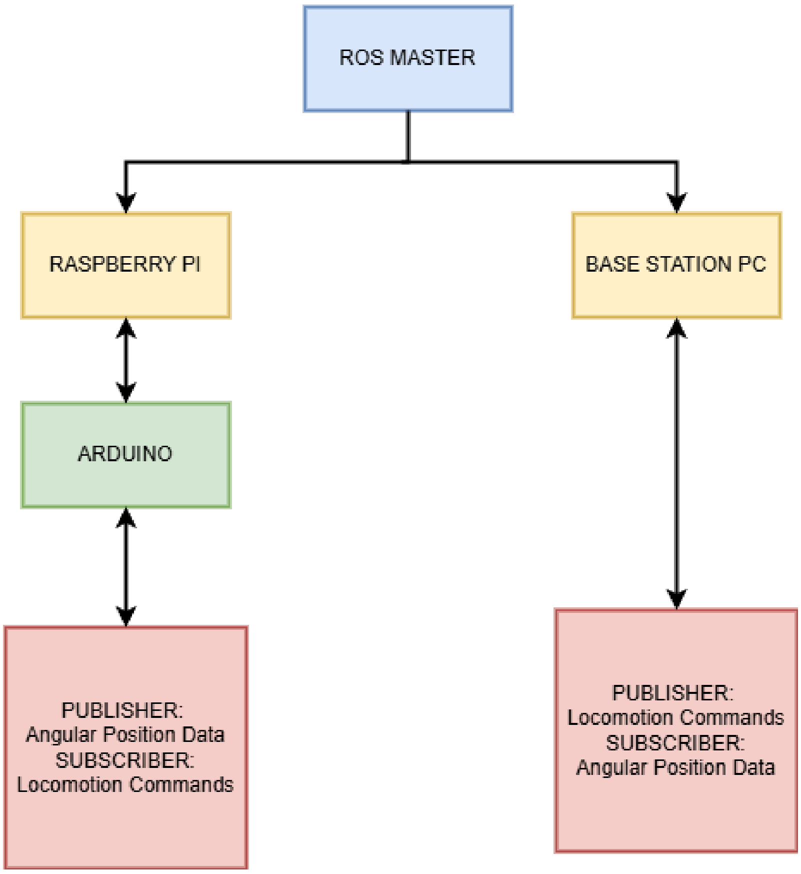


Figure 5.2 ROS Framework

The microprocessor would also facilitate the implementation of the Robotics Operating System (ROS) for simplified, user-friendly control of the arm. As depicted in the block diagram in figure 5.2, it will send and receive data from the individual microcontrollers and process the values to be stored and displayed for later use or PID plotting when necessary. The power subsystem, which is rechargeable, will ensure all the components have enough power to operate while the system is deployed within manholes, and the IMUs will send back data regarding the position of the joints as well as serve as input signals for the closed-loop PID-controlled system.

5.3 Evaluate the Solution to Meet Desired Need

The final developed hardware system is displayed below:

Figure 5.3 Working Prototype (Full View)

In figure 5.3 we see the full view of the working prototype of a 3 DOF arm for sewer maintenance. We can see the base rotation disk, the vision system, the links, and the motors.

Figure 5.4 Working Prototype (IP Cam and Base Rotation Mechanism)

Figure 5.4 places more emphasis on the stepper motor responsible for the base rotation mechanism. Also the vision system and the linear actuator used for link 2 is prominent.

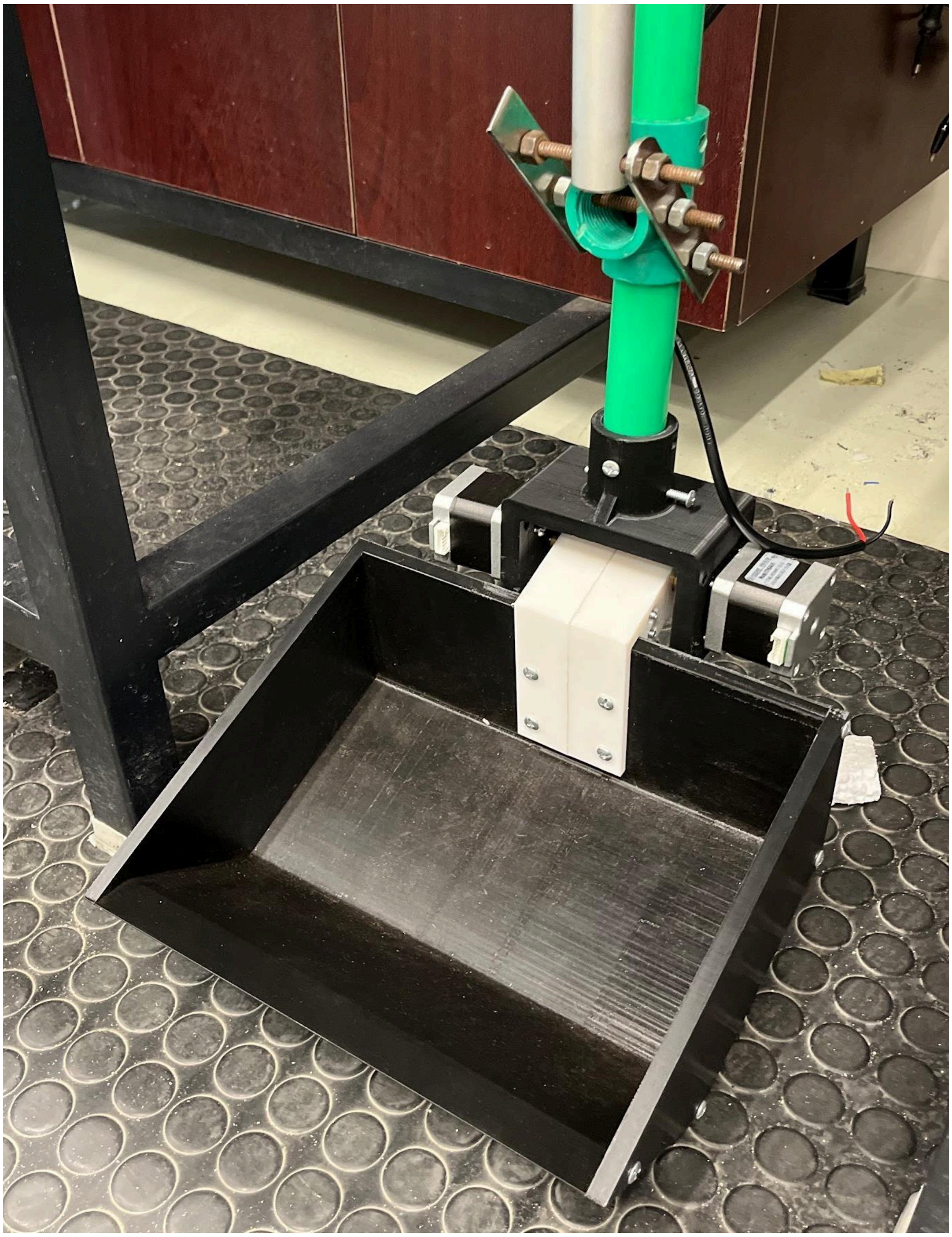
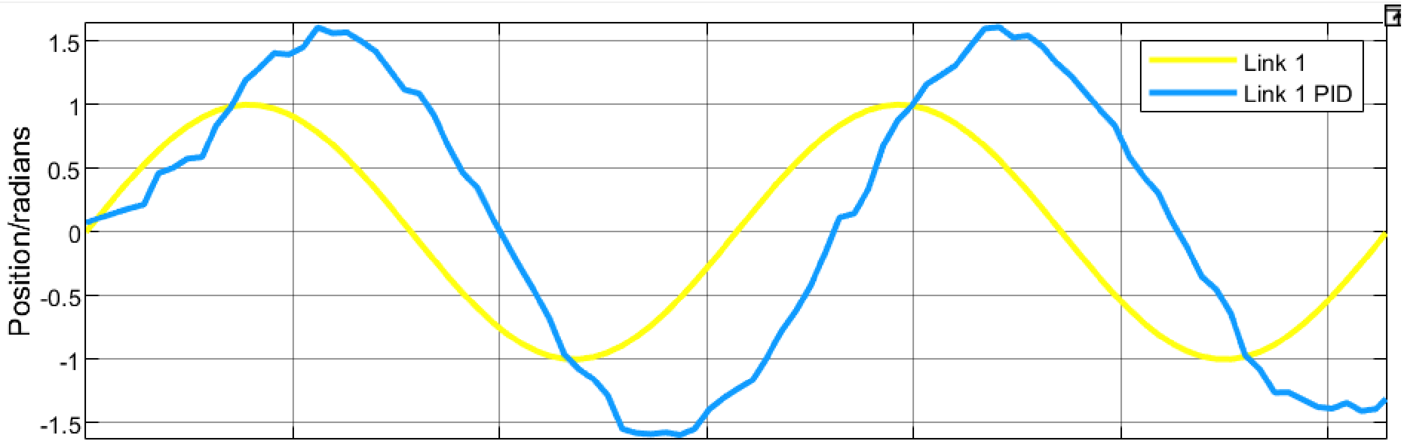


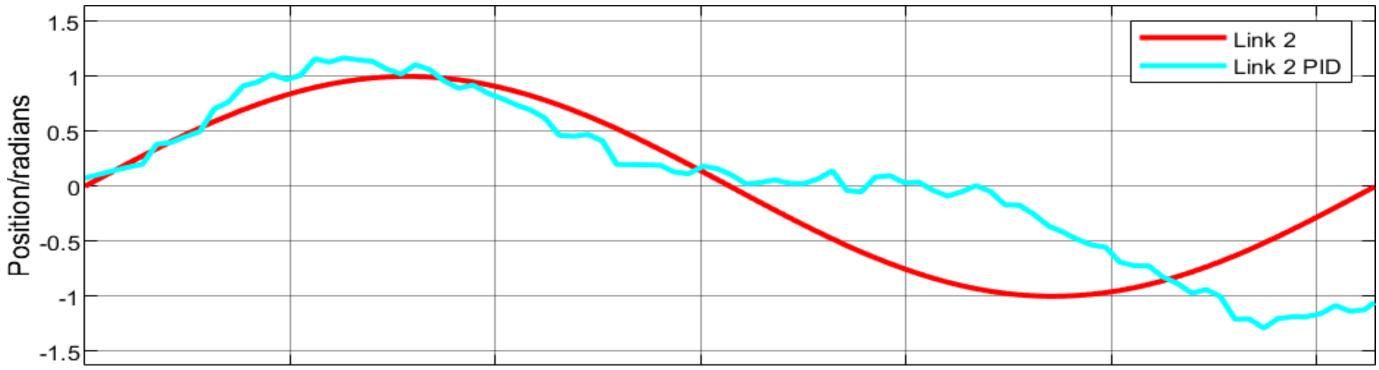
Figure 5.5 Working Prototype (Bucket)

In figure 5.5, we can see the end effector, which is a bucket that is to be used to scrape sewerage.

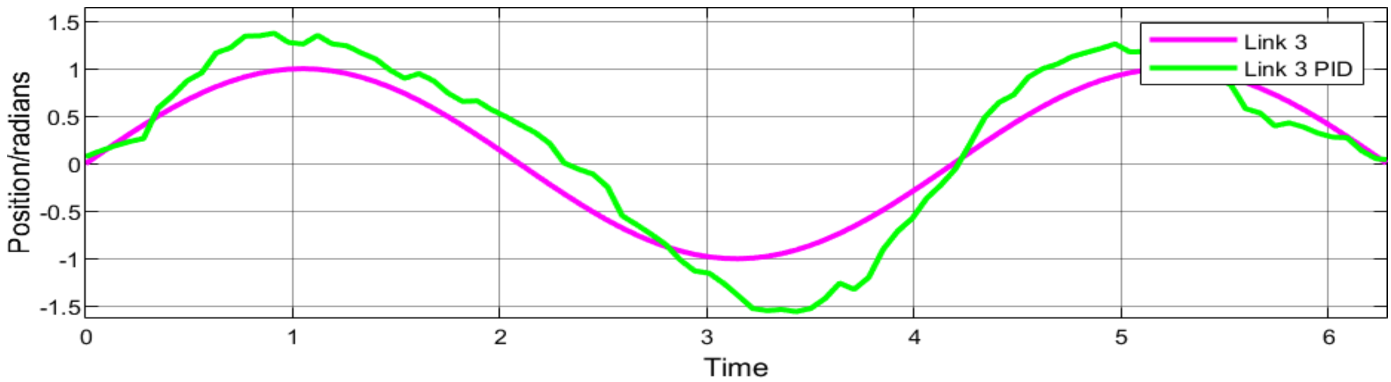
The system works, as intended, with all the functionalities and features defined in the requirements and objectives sections. The joints operate according to the angle provided by the user via the base station. The camera feed is also streamed live and provides a clear view of the bucket and its surroundings. The PID response of the joints has also been mapped and graphed, displayed below.



(a) Link 1



(b) Link 2



(c) Link 3

Figure 5.6 Practical PID Response

The PID response output for each individual joint or link, displayed in figure 5.6, is similar to the simulated response we had received (included in Chapter 4), although there are some irregularities and deviations, possibly due to noise in the system and some hardware- specific technical limitations and errors. By tuning the PID constants and using components with better specifications, we can further improve the response.

5.4 Conclusion

The final developed solution has thus been implemented, keeping the software design and optimized parameters in mind and it has been demonstrated that it successfully fulfills the complex engineering problem objectives and requirements laid out in the previous sections. It is necessary to mention, however, that the physical structure of the project during the time of writing this project, and by extension, the pictures depicted, do not include the feature of a completely waterproof external structure such that operation underwater or under semi-submersible liquid has not been demonstrated in this report. This leaves the waterproofing implementation to be left for future development and improvement, as discussed further in later sections.

Chapter 6: Impact Analysis and Project Sustainability. [CO3, CO4]

6.1 Introduction

This chapter evaluates the impact and sustainability of the proposed vision-based assistive robot for sewer maintenance in Bangladesh. It assesses the solution's effects on health, safety, environment, and socio-economic factors while analyzing its long-term viability and scalability to ensure alignment with sustainable development goals.

6.2 Assess the Impact of Solution

The vision-based assistive robot significantly mitigates risks associated with manual sewer maintenance. By automating blockage detection and removal, it reduces sanitation workers' exposure to toxic gases, pathogens, and hazardous conditions, decreasing health risks such as respiratory diseases and infections. Based on data from Bangladesh's sanitation sector, where 5–6 million workers face unsafe conditions, the robot could improve safety for thousands annually.

Environmentally, the solution enhances sewer system efficiency, reducing waterlogging incidents in Dhaka, where only 22% of the city's area has adequate drainage. This minimizes urban flooding, protecting ecosystems and reducing public health risks from stagnant water. Socio-economically, the robot creates opportunities for skilled jobs in robot operation and maintenance, while reducing reliance on low-wage, hazardous manual labor. Initial costs are offset by long-term savings from reduced healthcare expenses and flood-related damages, estimated at $100 million annually in Dhaka alone.

The project aligns with Sustainable Development Goals (SDGs), particularly SDG 6 (Clean Water and Sanitation) and SDG 8 (Decent Work and Economic Growth), by improving sanitation infrastructure and promoting safer working conditions. Compliance with ISO 45001 and OSHA 1910.146 ensures adherence to global safety standards, enhancing the solution's credibility and impact.

TABLE 6.1: SWOT ANALYSIS OF OPTIMAL DESIGN APPROACH

Strengths	Weaknesses
● Significantly minimizes health risks of workers ● Significantly lower cost of manufacturing and maintenance compared to machinery in contemporary use ● Less disruptive in terms of road and traffic mobility ● Can be adapted to different challenges by changing the end effector	● Complete waterproofing would be very costly ● Workers would require training to operate this system ● Will not be effective if blockage is at the middle of a pipe rather than the manhole section ● Maintenance cost might prove to be significant in the long run.
Opportunities	**Threats**
● Potential for government funding and support from NGOs ● The system can be altered to suit other countries' infrastructure if planned to be exported ● Will create new jobs for workers who will produce, operate and maintain this system	● The sudden sewage flow upon unclogging might damage the system ● The low-light and high-viscosity circumstances might render the system ineffective ● Unstable sewer infrastructure can damage the robot if it does not comply with the standards referred to when designing the system

As outlined in table 6.1, the possible strengths, weaknesses, opportunities and risks are as follows:

i) **Strengths:** If this project is accepted and deployed nationally, it will reallocate sewer cleaners to tasks such as operating the robot rather than having to dive into clogged sewers which has immense health risks, as described in the introduction. Not only will it prevent sickness and death, it can also save time and public funds because proper maintenance of sewers will reduce traffic disruptions and losses associated with sewage overflows. Moreover, the end-affector of the robot which is currently a bucket can be modified and replaced with a gripper or a drill if the circumstances become challenging and requires a different method for unclogging.

ii) **Weaknesses:** Given that most of the components that constitute this system are electronic and susceptible to water damage, complete waterproofing and regular testing as well as maintenance is necessary thereby increasing the cost of the system significantly. Furthermore, current design of the system does not allow for the maintenance of sewage pipes that connect the adjacent manhole chambers because the arm cannot extend that much, so the objective of the design itself might remain incomplete if such cases arise.

iii) **Opportunities:** The system has been designed keeping a very prevalent public issue such as the importance of public health and maintenance of public infrastructure in mind, so the potential for securing government or NGO support is considerable. Moreover, if it proves to be effective, safer and sustainable, the system can be offered for sale to other developing countries as well, which widens the scope of the system's application as well as adds to the return on investment and will facilitate further investment on research for improving this design.

iv) **Threats:** Conditions inside the manhole and sewer pipes and tunnels pose heavy risks to the proper operation of the robot; to be more specific, the low-light conditions will obstruct visibility, and possible heavy flow once the blockage has been removed can damage or loosen components, which can incur high repair costs for the system. Other possible threats include unstable underground infrastructure, which might collapse due to sustained pressure from the clog and deal damage to the robot as well as the operators handling the system.

6.3 Evaluate the Sustainability

The project's sustainability is evaluated across technical, economic, environmental, and social dimensions.

i) **Technical Sustainability:** The robot's design ensures durability in harsh sewer environments by using corrosion-resistant materials (per ASTM A967) and low-light cameras.. Modular components allow for easy maintenance and upgrades, extending the system's lifespan. Simulations in Fusion 360 and MATLAB Simulink confirm reliable performance, with power efficiency optimized for portable energy sources.

ii) **Economic Sustainability**: While initial development and deployment costs are high, the solution is cost-effective compared to imported systems like SIAR, with estimated Production costs 30–40% lower because of local manufacturing. Long-term savings from reduced flood damage and healthcare costs enhance economic viability. Partnerships with local governments and NGOs can secure funding and scalability.

iii) **Environmental Sustainability**: By improving drainage efficiency, the robot reduces untreated sewage overflow, protecting water bodies and ecosystems. Energy-efficient components minimize the carbon footprint, aligning with global environmental standards.

iv) **Social Sustainability**: The project empowers communities by training workers for technical roles, fostering social inclusion. Public awareness campaigns can address resistance to automation, ensuring stakeholder acceptance. The solution's adaptability to varying sewer dimensions makes it scalable to other developing nations with similar challenges.

6.4 Conclusion

The vision-based assistive robot offers transformative impacts by enhancing worker safety, reducing environmental risks, and promoting socio-economic benefits. Its sustainable design ensures long-term viability through technical reliability, economic feasibility, and environmental responsibility. By addressing critical sanitation challenges in Bangladesh and aligning with global standards and SDGs, the project sets a precedent for innovative, sustainable urban sanitation solutions, with potential for widespread adoption in developing regions.

Chapter 7: Engineering Project Management [CO11, CO14]

7.1 Introduction

We planned, examined, and executed our project over a year during our final year design project timeline. In the first semester, we did necessary planning and researched various project management software like JIRA, Trello, and ClickUp to keep our ATC and each other updated about our regular work and have a smooth work division among the group. There were some successive changes as we proceeded through each stage of the project. Those were mentioned in the FYDP logbook attached in the appendix, and all changes were carried out keeping our originally planned FYDP timeline and responsibility matrix in mind

7.2 Project Timeline

The estimated timeline of the project is one year, divided within three semesters, as outlined below in the form of Gantt charts.

Table 7.1: FYDP P Timeline

Tasks	Week														
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
Topic Selection															
Literature Review															
Market Survey															
Draft Note Preparation															
Designing Multiple Approaches															
Risk Assessment															
Ethics and sustainability															
Proposal Preparation															

TABLE 7.2: FYDP D TIMELINE

Tasks	Week													
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*
Refine Designs														
Design 1 Simulation														
Design 2 Simulation														
Analysis and Comparison														
Selection of approach														
Final Presentation and Report														

TABLE 7.3: FYDP C TIMELINE

Tasks	Week													
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*
Acquiring Resources														
Design Implementation														
Testing and Refining														
Performance analysis														
Final Project Demonstration														

7.3 Conclusion

According to the predicted timeline, the project was carried out and completed within the given time frame and the responsibilities were distributed and executed in an efficient and productive manner. Despite slight delays due to unavoidable circumstances such as political unrest and changes in government holiday plans, the project was able to be implemented on time and with the expected results.

Chapter 8: Economical Analysis. [CO12]

8.1 Introduction

This chapter presents an economic analysis of the vision-based assistive robot for sewer maintenance in Bangladesh. It evaluates the project's financial viability through cost-benefit analysis and examines economic and financial aspects to assess its feasibility and long-term impact on urban sanitation infrastructure. It must be noted that since this is not a consumer product or aimed for the general public, the economic analysis for this device will be more in terms of the benefits versus cost for the state as well as the workers currently affected by the problem statement we are seeking to solve through the implementation of this device.

8.2 Cost-benefit Analysis

The economic analysis highlights the robot's potential to address inefficiencies in Bangladesh's sewer maintenance system, particularly in Dhaka, where flooding causes annual economic losses of approximately BDT 12 crore (BDT 120 million). Manual sewer cleaning, employing 5–6 million workers, incurs high costs due to health-related expenses and productivity losses from unsafe working conditions. The robot aims to reduce these costs by automating hazardous tasks, improving drainage efficiency, and minimizing flood-related damages.

Economic benefits include reduced healthcare costs for sanitation workers and decreased flood damage expenses. Additionally, the robot creates opportunities for skilled employment in robot operation and maintenance, contributing to economic growth. The solution aligns with Sustainable Development Goal 8 (Decent Work and Economic Growth) by promoting safer, higher-value jobs.

TABLE 8.1: COST CALCULATION

Cost of Production for Robotic Arm			
Component	***Component specification***	***Quantity***	***Price (Tk)***
IP camera	(12 VDC); 3.5 W (PoE);IP67	1	3200
Relay Module	10A 30VDC; Operating 12V;8 channel	2	1420
Linear Actuato r	12V DC 100mm 900N 90KG	8	35600
Arduino Mega	16MHz; 6-12VDC	1	1895

Buck Converter	15W; Input4.5-35V; Output 3-35V	1	440

Cost of Production for Robotic Arm			
Component	***Component specification***	***Quantity***	***Price (Tk)***
Boost Converter	150W;20A;Inpu t10-32V;Output12-35V	1	305
LiPo Battery	3300mah;11.1V	1	3490
Switch	4Port; PoE	1	2900
SBC	Raspberry Pi	1	15000
Miscellaneous	-	-	9725
Total			73,975

TABLE 8.2: COST-BENEFIT CALCULATION

Costs	
Factor	**Cost (BDT)**
Cost of Production (assuming 10 robots)	739,750
Testing	12,000
Training Operators	8,000
Maintenance of robot (sustain waterproofing, replacement of parts/battery)	55,000
Rent and salary (storage, maintenance, operation)	80,000
TOTAL COSTS	**2,289,750**
Benefits	
Reduced rate and intensity of sewer flooding, saving unclogging costs	12,000,000
Saved economic costs by preventing traffic disruptions	23,00,000
Reduced health complications and diseases for workers	12,000,000
TOTAL BENEFITS	**17,500,000**
Benefit-Cost Ratio (Benefits/Costs)	**60.4%**

Therefore, it is evident that the benefit received through the implementation of this project on a national level is much greater than the combined direct and indirect costs of producing and maintaining this system for sewer maintenance. Given the nature of the purpose of this project as a safety enhancement tool as well as a public good that benefits not only the user but also the society and the environment to a much greater extent, it is believed that this system should be bought and funded by the government, so the cost benefit and ROI calculation take on a different perspective and angle than general consumer goods would.

8.3 Return on Investment (ROI)

TABLE 8.3: TOTAL PROJECTED PRICE CALCULATION

Subsystem	Cost (BDT)	Projected Price including markup 15% (BDT)
Microprocessor	15,000	17,250
Vision	4,500	5,175
Base Station	7,000	8,050
Mechanical	23,450	26,970
Electronics	18,970	21,815
Power	8,200	9,430
Total	**77,120**	**90,075**

The manufacturing and assembly cost per robot (BDT 77,120) is compared to the projected price set by discussing appropriate markups (15%) on individual subsystems, resulting in a Return on Investment (ROI) of 16.8%. With an estimated lifespan of 3 years, the robot's annual ROI is 5.6%**.** Assuming a bulk production of 100 units, reduction of per unit cost becomes [- 20%] which is BDT 39,600 such that, if the market price is kept unchanged, the updated ROI will be 46%.

It is worthy mentioning that the relevant cost benefit analysis in this case would be to weigh the cost of this system against the physical harm and health damage suffered by sewer cleaners, which is difficult to put a price on. It is hoped that this project will be funded by the federal government and employed as the standard for sewer maintenance methods, thereby eliminating the need for market price considerations and consumer demand concerns.

8.4 Evaluate Economic and Financial Aspects

The procurement of parts and manufacturing, as well as the assembly of the robots will require high investment at the beginning as well as considerable space for production and storage. Although the durability and fragility of the system and hardware are not very sensitive to environmental factors such as light, temperature, and pressure, which reduces its storage costs, it does require constant maintenance and upkeep to ensure its wiring and electronics are in proper operating condition. All in all, the production and maintenance of this system, despite its initial costs, is very inexpensive and easy to maintain compared to the current prevalent system in use (large chamber vehicles).

8.5 Conclusion

The vision-based assistive robot is economically and financially viable, offering substantial benefits through healthcare savings, flood damage reduction, and job creation. The cost-benefit analysis confirms a high return on investment, with a payback period of less than one year and a strong NPV. By leveraging local production and aligning with global development goals, the project ensures long-term economic sustainability, making it a transformative solution for urban sanitation in Bangladesh and beyond.

Chapter 9: Ethics and Professional Responsibilities CO13, CO2

9.1 Introduction

This chapter examines the ethical issues and professional responsibilities associated with the development and deployment of the vision-based assistive robot for sewer maintenance in Bangladesh. It identifies key ethical considerations and outlines how these principles are applied to ensure the project aligns with professional standards and societal values, prioritizing worker safety, environmental sustainability, and social equity.

9.2 Identify Ethical Issues and Professional Responsibilities

The development and implementation of the assistive robot raise several ethical issues and professional responsibilities:

i) **Worker Safety and Health**: Manual sewer cleaning exposes workers to hazardous conditions, including toxic gases and pathogens. The robot aims to reduce these risks, but its deployment must ensure no workers are displaced without alternative employment opportunities. Professional responsibility includes adhering to ISO 45001 (Occupational Health and Safety) and OSHA 1910.146 (Confined Spaces) to prioritize worker well- being.

ii) **Social Equity and Job Displacement**: Automation may reduce manual labor jobs, potentially affecting the livelihoods of 5–6 million sanitation workers in Bangladesh. Ethical concerns involve ensuring fair transition plans, such as retraining programs for technical roles. Professional responsibility requires transparent communication with stakeholders to address concerns about job security.

iii) **Environmental Impact**: The robot's operation must minimize environmental harm, such as preventing sewage leaks or equipment disposal issues. Professional responsibility includes compliance with ASTM A967 for corrosion-resistant materials to reduce environmental degradation and adherence to environmental regulations.

iv) **Data Privacy and Security**: The robot's real-time video feed and sensor data require secure handling to prevent misuse. Ethical considerations include protecting data from unauthorized access, while professional responsibility involves implementing robust cybersecurity protocols, such as encrypted communication (e.g., CAN Bus or Ethernet).

v) **Cost and Accessibility**: The robot must be affordable and accessible to municipalities in developing nations. Ethical issues arise if high costs limit deployment to wealthier areas, exacerbating inequalities. Professional responsibility includes designing cost-effective solutions, leveraging local manufacturing to reduce costs by 30–40% compared to imported systems like SIAR.

vi) **Accountability and Reliability**: The robot's failure could lead to sewer blockages or safety hazards. Professional responsibility requires rigorous testing (e.g., using Fusion 360 and MATLAB Simulink simulations) to ensure reliability and accountability for any operational failures

9.3 Distribution of Professional Responsibilities and Risk Management

The project has also been divided uniformly into the most essential tasks to allow for greater efficiency and collaboration between members. The delegation of the duties are outlined below:

Table 9.1: Responsibility Assignment Matrix

Tasks	**Responsibilities**			
	Responsible	***Accountable***	***Consulted***	***Informed***
Literature Review	Marufa	Tagabun	Zaiyan	Tasfiq
Market Research	Tagabun	Tasfiq	Marufa	Zaiyan
Simulation of designs	Zaiyan	Tasfiq	Tagabun	Marufa
Budget Preparation and Resources Procurement	Tasfiq	Marufa	Zaiyan	Tagabun
Constructing Hardware Prototype	Zaiyan	Tasfiq	Tagabun	Marufa
Testing and Analysis	Marufa	Tagabun	Zaiyan	Tasfiq
Risk Assessment	Tagabun	Marufa	Tasfiq	Zaiyan

Beyond project responsibilities, we also have a responsibility to mitigate and account for possible risks associated with the development of this project, the details and assignment of which is mentioned in the table below.

TABLE 9.2: RISK RESPONSE MATRIX

Risk Event	Response	Contingency Plan	Trigger	Responsible?
Water damange to electronics	Mitigate: Use waterproof housings	Use backup electronics, isolate damage	Signs of water exposure on sensitive parts	Zaiyan
Camera malfunction	Mitigate: Test camera in low light conditions	Use backup camera	Image quality drops below acceptable range	Tagabun
Mechanical obstruction in pipes	Mitigate: Use adaptable robotic joints	Manual removal or bypass	Robot fails to move forward	Marufa
Software bugs in control system	Accept: Testing and manual override	Reboot system or switch to manual control	Robot fails to respond to commands	Zaiyan
Component failure	Transfer: Use component warranties	Replace damaged components with spares	Robotic arm stops functioning	Tasfiq

Upon assessment of the possible risks associated with the project during its development as well as its testing and deployment, it has been discovered that some of the most common risks involve malfunctioning of components due to water or collision damage and software failures that can arise from communication or processing inadequacies. The subsequent mitigation strategies have also been discussed and responsibilities assigned to each member according to table 9.3.2 to ensure safety and accuracy is upheld.

9.4 Apply Ethical Issues and Professional Responsibilities

To address these ethical issues and fulfill professional responsibilities, the following measures are implemented:

i) **Worker Safety and Retraining**: The project prioritizes worker safety by automating hazardous tasks, reducing exposure to dangerous conditions. A retraining program is established to transition manual workers to roles such as robot operators or maintenance technicians, ensuring no loss of livelihood. Partnerships with local NGOs facilitate skill development, aligning with SDG 8 (Decent Work and Economic Growth).

ii) **Stakeholder Engagement**: Transparent communication with sanitation workers, local communities, and government bodies addresses concerns about job displacement and ensures inclusive decision-making. Public awareness campaigns highlight the robot's benefits, fostering community support.

iii) **Environmental Sustainability**: The robot uses corrosion-resistant materials and energy-efficient components to minimize environmental impact. Regular maintenance schedules prevent equipment degradation, and disposal protocols comply with environmental regulations to avoid pollution.

iv) **Data Security**: Encrypted communication protocols (e.g., CAN Bus) and secure data storage systems protect video feeds and sensor data. Regular cybersecurity audits ensure compliance with international data protection standards.

v) **Affordability and Scalability**: Local manufacturing reduces production costs to approximately BDT 24,000 per unit, making the robot accessible to municipalities. Funding from government grants and international agencies, such as the World Bank, supports widespread deployment, ensuring equitable access.

vi) **Reliability and Accountability**: Extensive simulations and testing (e.g., Fusion 360 for kinematics, MATLAB Simulink for power efficiency) ensure the robot's reliability. A clear accountability framework assigns responsibility to developers and operators for addressing operational failures, with regular performance reports shared with stakeholders.

9.5 Conclusion

The vision-based assistive robot for sewer maintenance upholds ethical principles and professional responsibilities by prioritizing worker safety, social equity, environmental sustainability, and data security. Through retraining programs, stakeholder engagement, and cost-effective design, the project addresses ethical concerns while fulfilling professional obligations. By adhering to international standards and fostering inclusivity, the robot sets a benchmark for ethical engineering, delivering a sustainable and equitable solution for urban sanitation in Bangladesh and beyond

Chapter 10: Conclusion and Future Work.

10.1 Project summary/Conclusion

This project aimed to design and implement a relatively low-cost, vision- assisted robotic system for sewer maintenance that is much safer and efficient than contemporary methods as well as easy-to-use. It has been demonstrated that the system works as expected as it shows proper incorporation of real-time monitoring and remote control from the base station for enhanced safety and ease of operation. Care has been taken to ensure the commands are easy to give and control and operation of the system is intuitive enough to reduce the need for intensive training for familiarization with the system. Expected outcome from this project is the standardized implementation of this system across the country for sewer cleaning and maintenance in order to eliminate the need for underpaid workers to risk their lives and well-being.

10.2 Future work

Since the robot is currently manually controlled, it is possible to work on automation by using the live camera feed for image processing and machine learning. The PID Response of the links can also be improved further by tuning the parameters and testing for accurate results and operation. It may also be possible to make the end-effector detachable and keep multiple choices for the end-effector action, such as a gripper, if necessary. The deployment process of the robot within manholes can also be made more efficient if a rigid pulley system can be designed that would make the setup procedure more efficient and easier.

Chapter 11: Identification of Complex Engineering Problems and Activities.

Since the project is centered around designing a solution for maintenance of sewer systems to avoid and overcome clogging and overflowing issues, two possible solutions have been suggested, assessed and analysed which shows that it is an open-ended problem with numerous possible ways to fix it. The solutions discussed above, in particular, prove that it is a complex engineering problem because they both require depth of knowledge regarding the technical requirements and specifications of the problem as well as familiarity regarding the matter being resolved. The sub-systems being developed are dependent on each other and each of them require in-depth analysis to assess their functionality. There are many applicable codes and standards related to the solution since it will operate on a public civil infrastructure.

Apart from that, these innovative solutions involve a wide range of resources, both hardware and software, for successful implementation and the application of any one of these would have consequences for the society, the economy, and the environment, all of which are components of complex engineering activities.
After research and simulations, it has been observed that the solution more suitable for this problem is the use of a robotic arm with a bucket as the end effector for scooping out the sewage and sludge that clogs up sewers. In the completion phase of the FYDP, this system will be constructed and tested for implementation.

11.1 Attributes of Complex Engineering Problems (EP)

	Attributes	**Put tick (√) as appropriate**
P1	Depth of knowledge required	✔
P2	Range of conflicting requirements	✔
P3	Depth of analysis required	✔
P4	Familiarity of issues	✔
P5	Extent of applicable codes	✔
P6	Extent of stakeholder involvement and needs	
P7	Interdependence	✔

Note: Project must have P1, and some or all from P2-P7

11.2 Attributes of Complex Engineering Activities (EA)

	Attributes	**Put tick (√) as appropriate**
A1	Range of resource	✔
A2	Level of interaction	
A3	Innovation	✔
A4	Consequences for society and the environment	✔
A5	Familiarity	✔

Note: Project must have some or all of the characteristics from attributes A1 to A5

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Appendix

FYDP Logbook

	Final Year Design Project		
Student Details	**NAME & ID**	**EMAIL ADDRESS**	**PHONE**
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ATC Details:			
ATC 6			
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Member 1	Sharif Mohammad Shams	sharif.mohd@bracu.ac.bd	
Member 2	Nahid Hossain Taz	nahid.hossain.taz@bracu.ac.bd	

Date/Time /Place	Attendee	Summary of Meeting Minutes	Responsible	Comment by ATC
18.06.2024 (Weekly ATC Meeting)	1. Zaiyan 2. Tagabun 3. Tasfiq 4. Marufa	1. Introduction to FYDP 2. Proposed various problem statements	All	
25.06.2024 (Weekly ATC meeting)	1. Zaiyan 2. Tagabun 4.Marufa	1. Decide on an appropriate problem statement	All	
02.07.2024 (Weekly ATC meeting)	1. Zaiyan 2. Tagabun 3. Tasfiq 4. Marufa	1. Discussion about selected topic 2. Perform literature review 3. Decide what contents to be included in progress presentation	All	
03.09.2024 (Weekly ATC meeting)	1. Zaiyan 2. Tagabun 3. Tasfiq 4. Marufa	1) First meeting with ATC after the July movement. 2) Discussion about creating another design approach , research and looking over relevant papers 3) Learned that one of the ATC members will be leaving soon for a PhD abroad.	Task 2: All	
15.09.2024 (Additional ATC consultation)	1. Zaiyan 2. Tagabun 3. Tasfiq 4. Marufa	1) Proposal to change our previous topic 2) Suggestion by ATC to research on some topics and find a problem	Task 2: All	
17.09.2024 (Weekly ATC meeting)	1. Zaiyan 2. Tagabun 3. Tasfiq 4. Maru	1) Presented some narrowed down topics to the ATC 2) ATC pointed out some constraints of our suggested topic 3) Further background	Task 3: All	

	fa	research on the topics and derive a specific problem statement		
19.09.2024 (Additional ATC consultation)	1. Zaiyan 2. Tagabun 3. Tasfiq 4. Marufa	1) Reached to a conclusion that our previous suggested topics aren't feasible enough and does not have a proper problem statement 2) ATC suggested one last research on two selected topics before final presentation	All	
22.09.2024 (Additional ATC consultation)	1. Zaiyan 2. Tagabun 3. Tasfiq 4. Marufa	1) Finalized our topic 2) ATC suggested to look over design approaches and provide a background research until the next meeting	All	
24.09.2024 (Weekly ATC consultation)	1. Zaiyan 2. Tagabun 3. Tasfiq 4. Marufa	1) Discussed the design approaches with the ATC 2) Discussion on our project and how it is feasible and the scopes, objectives of it	Task 1: Zaiyan Task 2: Marufa, Tasfiq, Tagabun	
FYDP D				

31.10.24	1. Zaiyan 2. Tagabun 3. Tasfiq 4. Marufa (ABS)	1. Initial Progress on Kinematics 2. Learning Fusion 360 Component Construction 3. Preliminary Power Budget		1) Incorporation of the claw part pending. 2) Must do some literature review on the power details.
23.11.24	1. Zaiyan 2. Tagabun 3. Tasfiq 4. Marufa	1. Current progress on kinematics 2. Progress of 3D design (base done) 3. Updated power budget 4. Proteus simulation for motor controls		1) Try to calculate volume capacity 2) Estimation of power consumpti

				on based on robot's round trips
12.12.24	1. Zaiyan 2. Tagabun 3. Tasfiq 4. Marufa	1. Pressure and power calculation of pump for assumed amount of sludge to compare with approach 1 2. Also calculate time taken for both approach 3. 3D modeling and completing the control part of design -1	1. Marufa 2. Tasfia 3. tagabun and zaiyan	
19.12.24	1.Zaiyan 2.Tagabun 3. Tasfiq 4. Marufa	1. Progress update on simulations 2. Discussion regarding possible improvements in the simulations 3. Beginning to learn Robot Operating Systems for FYDP C	1. All 2. All 3. Zaiyan and Marufa	
2.1.25	1.Zaiyan 2.Tagabun 3. Tasfiq 4. Marufa	1. Begin preparing slides for Final Presentation 2. Divide sections for presentation	1. All 2. All	
9.12.25	1.Tagabun 2. Tasfiq 3.Marufa	1. Inform ATC regarding feedback on Final Presentation	1. All	1) Stay updated on each other's tasks and pick up and continue the task in case any member is unavailable 2) Make both qualitative and quantitative comparisons between design

				approaches supported by simulations and literature review
14.1.25	1.Zaiyan 2.Tagabun 3. Tasfiq 4. Marufa	1. Update regarding progress on Design Report 2. Proper writeup in report regarding 3D modelling and assembly 3. Writeup regarding Robotic Arm PID simulation 4. Writeup regarding Cost and Payload comparison between approaches 5. Writeup regarding communication establishment and protocols for the robotic arm	1. All 2. Tagabun 3. Zaiyan 4. Tasfiq 5. Marufa	
		FYDP - C		
22/03/25 (FYDP Lab)	1. zaiyan 2. Tagabun 3. Tasfiq 4. Marufa	1. Tested IMU functionality	1. Marufa	
23/03/25 FYDP Lab	1. zaiyan 2. Tagabun 3. Tasfiq 4. Marufa			
24/03/25 (FYDP Lab)	1. zaiyan 2. Tagabun 3. Tasfiq 4. Marufa	1. Tried to interface arduino with Raspberry Pi	1. Zaiyan, Marufa	

25/03/25 (FYDP Lab)	1. zaiyan 2. Tagabun 3. Tasfiq 4. Marufa	1. Tried to assign static IP to webcam and access from base station 2. Tested functionality of Motors and Motor drivers	1. Marufa 2. Tasfiq	
Mar 28, 2025	1. zaiyan 2. Tagabun 3. Tasfiq 4. Marufa	1. Online meeting to plan April goals and finalize remaining components	1. Zaiyan 2. Tagabun 3. Marufa 4. Tasfiq	
Apr 3, 2025	1. zaiyan 2. Tagabun 3. Tasfiq 4. Marufa	1. Sat together and worked on design report sections	5. Zaiyan 6. Tagabun 7. Marufa 8. Tasfiq	
Apr 4, 2025	All	1. Tested control functionality and verified 3D mechanical joints	1. Zaiyan 2. Tagabun	
Apr 8, 2025	All	1. Online call to finalize communication protocol documentation	1. Marufa	

Apr 10, 2025	All	1. Focused on refining motor control logic and debugging	1. Tasfiq 2. Tagabun	
Apr 13, 2025	All	1. Discussed design updates and integration steps in online session	All	
Apr 16, 2025	All	1. Tested integrated system with partial subsystems in lab	All	
Apr 18, 2025	All	1. Troubleshooting power fluctuation in motor	2. Tasfiq	

		driver		
Apr 21, 2025	All	1. Assembled claw and arm modules; tested rotational control	2. Zaiyan 3. Tagabun	
Apr 23, 2025	All	1. Online meeting to prepare upcoming progress documentation	2. Tagabun 3. Marufa	
Apr 25, 2025	All	1. Debugging communication between Raspberry Pi and microcontroller in lab	2. Marufa 3. Zaiyan	
Apr 28, 2025	All	1. Evaluated power efficiency of system during testing	2. Tasfiq	
Apr 30, 2025	All	1. Started compiling experimental data and logs for report	All	
May 2, 2025	All	1. Final mechanical alignment checks before full integration and 3D printed parts	2. Zaiyan 3. Tagabun	
May 5, 2025	All	1. Conducted full system test and documented performance	All	
May 8, 2025	All	1. Online review of report drafts and task reassignment	All	
May 11, 2025	All	1. Final tests on robotic arm communication and response accuracy	All	
May 13, 2025	All	1. Summary and final write- up of system functionalities	All	
May 14, 2025	All	1. Prepared a preliminary draft of the final report and made a working video for the exhibition day.	All	

Related code/theory

ARDUINO CODE FOR ROS:

```
#include <ros.h>
#include <std_msgs/Int32.h>
#include <geometry_msgs/Twist.h>



//PIN ASSIGNMENT
// Pin definitions for A4988 driver

const int wrPWMleft = 5;
const int wrPWMright = 6;

// Elbow pin

const int elPWMleft = 9;
const int elPWMright = 10;

const int enPinBs = 2;
const int dirPinBs = 3;
const int stepPinBs = 4;

// Motor parameters
```

```
const float stepsPerRevolution = 200; // NEMA 17 & 23 typically
1.8° per step (200 steps/rev)
const float microsteps = 16;          // A4988 set to
16 microsteps
const float stepsPerDegree = (stepsPerRevolution * microsteps) /
360.0;
//LINUX_INPUT_VARIABLES
int baseAngle_inp = 0;

int cmdVelelbow=0;
int cmdVelwrist=0;

ros::NodeHandle nh;
//for input angle to motor
void cbWrist(const geometry_msgs::Twist &wristROS){
  cmdVelwrist = round(wristROS.linear.x);
}

void cbElbow(const geometry_msgs::Twist &elbowROS){
  cmdVelelbow = round(elbowROS.linear.x);

}

void cbBase(const std_msgs::Int32 &baseROS){
  baseAngle_inp=baseROS.data;
}
//for IMU readings
std_msgs::Int32 wristIMU_ROS;
ros::Publisher wristROS_pub("wristAngle_m", &wristIMU_ROS);

std_msgs::Int32 elbowIMU_ROS;
ros::Publisher elbowROS_pub("elbowAngle_m", &elbowIMU_ROS);

std_msgs::Int32 baseIMU_ROS;
ros::Publisher baseROS_pub("baseAngle_m", &baseIMU_ROS);

//subscribes to INPUT FROM LINUX
ros::Subscriber<geometry_msgs::Twist> wristROS_cmdVel("wristVel",
&cbWrist);
ros::Subscriber<geometry_msgs::Twist> elbowROS_cmdVel("elbowVel",
&cbElbow);
ros::Subscriber<std_msgs::Int32> baseROS_sub("baseAngle",
```

```
&cbBase);

void setup()
{
  pinMode(wrPWMleft, OUTPUT);
  pinMode(wrPWMright, OUTPUT);
  pinMode(elPWMleft, OUTPUT);
  pinMode(elPWMright, OUTPUT);

  pinMode(enPinBs, OUTPUT);
  pinMode(dirPinBs, OUTPUT);
  pinMode(stepPinBs, OUTPUT);

  //digwrite
  digitalWrite(enPinBs, HIGH);

  nh.initNode();

  nh.advertise(wristROS_pub)
  ;
  nh.advertise(elbowROS_pub)
  ;
  nh.advertise(baseROS_pub);

  nh.subscribe(wristROS_cmdVel);
  nh.subscribe(elbowROS_cmdVel);
  nh.subscribe(baseROS_sub);
}

void loop()
{
  nh.spinOnce();
  //use input values to write
  //WRIST
  if (cmdVelwrist > 0) {
     analogWrite(wrPWMleft, 50);
  }
  else if(cmdVelwrist == 0)
  {
     analogWrite(wrPWMleft, 0);
     analogWrite(wrPWMright, 0);
  }
  else {
```

```
analogWrite(wrPWMright, 50);
```

```
  }
  //ELBOW
  // Move motor
 if (cmdVelelbow > 0) {
     analogWrite(elPWMleft, 255);
  }
  else if(cmdVelelbow == 0)
  {
     analogWrite(elPWMleft , 0);
     analogWrite(elPWMright, 0);
  }
  else {
     analogWrite(elPWMright, 255);
  }


  //BASE
  digitalWrite(enPinBs, HIGH);
  int steps = (long)(baseAngle_inp * stepsPerDegree); // Set
direction
  if (steps >= 0) {
     digitalWrite(dirPinBs, HIGH); // Clockwise
  } else {
     digitalWrite(dirPinBs, LOW);   // Counterclockwise
     steps = -steps;
  }
  // Move motor
  for (long i = 0; i < steps; i++) { //steps --> 32000
     digitalWrite(stepPinBs, HIGH);
     delayMicroseconds(500); // Adjust for motor speed
     digitalWrite(stepPinBs, LOW);
     delayMicroseconds(500);
  }
  baseAngle_inp = 0;
  //IMU values publish
  wristIMU_ROS.data=0; //value
  elbowIMU_ROS.data=0; //value
  baseIMU_ROS.data=0; //value


  wristROS_pub.publish(&wristIMU_ROS);
  elbowROS_pub.publish(&elbowIMU_ROS);
```

```
  baseROS_pub.publish(&baseIMU_ROS);

  delay(100);

}
```

ROS CODE ON BASE STATION:

1. **base rotation ros publisher** #!/usr/bin/env python3 import rospy

```
from std_msgs.msg import Int32


nodeName='anglePublisher'

topicNameBase='baseAngle'

rospy.init_node(nodeName, anonymous=True)


publisherBase=rospy.Publisher(topicNameBase, Int32, queue_size=5)

ratePublisher=rospy.Rate(1)

thetaWrist=
0
thetaElbow=
0
thetaBase=0

while not rospy.is_shutdown():
      rospy.loginfo(thetaBase)

      thetaBase = int(input('Enter base rotation angle: \n'))
      publisherBase.publish(thetaBase)

      ratePublisher.sleep()
```

2. **wrist publisher**

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

```
import rospy
from geometry_msgs.msg import Twist
import sys
import select
import tty
import termios

# Instructions for user
msg = """
Control Your Robot!
---------------------------

i/, : move
forward/backward k   :
stop
t   : emergency stop (set all velocities to
0) anything else : stop

CTRL-C to quit
"""

# Key bindings
bindings = {
     'i': (1.0, 0.0),   # Forward
     ',': (-1.0, 0.0),  # Backward
     'm': (0.0, 1.0),   # Turn left
     '.': (0.0, -1.0),  # Turn right
     'u': (0.1, 0.0),   # Increase linear velocity
     'o': (-0.1, 0.0),  # Decrease linear velocity
     'j': (0.0, 0.1),   # Increase angular velocity
     'l': (0.0, -0.1),  # Decrease angular velocity
     'q': (0.1, 0.1),   # Increase speed multiplier
     'z': (-0.1, -0.1), # Decrease speed multiplier
     'k': (0.0, 0.0),   # Stop
     't': (0.0, 0.0) # Emergency stop
}

def getKey():
     # Get a single character from stdin without requiring Enter
     old_settings = termios.tcgetattr(sys.stdin)
     try:
     tty.setcbreak(sys.stdin.fileno())
     if select.select([sys.stdin], [], [], 0.1)[0]:
```

```
            return sys.stdin.read(1)
        return None
        finally:
        termios.tcsetattr(sys.stdin, termios.TCSADRAIN, old_settings)

def main():
        rospy.init_node('wrist_teleop_keyboard',
        anonymous=True)   pub   =   rospy.Publisher('/wristVel',
        Twist, queue_size=10) rate = rospy.Rate(10) # 10 Hz

        # Initial values
        linear_x = 0.0
        angular_z = 0.0
        speed_multiplier = 1.0
        max_linear = 0.5   # Max linear velocity (m/s)
        max_angular = 1.0 # Max angular velocity (rad/s)

        # Print instructions
        print(msg)

        while not rospy.is_shutdown():
        key = getKey()
        twist = Twist()

        if key in bindings:
            linear_change, angular_change = bindings[key]

            if key in ['i', ',', 'm', '.', 'k', 't']:
                # Direct motion commands
                linear_x = linear_change * max_linear *
speed_multiplier speed_multiplier   angular_z =
                                    angular_change *
                                    max_angular * if key ==
                                    't':
                                    linear_x = 0.0
                                    angular_z =
                                    0.0
                                    print("Emer
                                    gency
                                    Stop!")
            elif key in ['u', 'o', 'j', 'l']:
                # Adjust base velocities
                linear_x += linear_change * speed_multiplier
                angular_z += angular_change * speed_multiplier
```

```
linear_x = max(min(linear_x, max_linear), -
```

```
max_linear)                               angular_z = max(min(angular_z,
                                          max_angular), -
max_angular)

                                            elif key in ['q', 'z']:
                                                 # Adjust
                                                 speed
                                                 multiplier
2.0))                                            speed_mult
                                                 iplier +=
                                                 linear_cha
                                                 nge
                                                 speed_multiplier = max(0.1,

                                                 min(speed_multiplier,

                                                 print(f"Speed multiplier:

                                                 {speed_multiplier:.2f}")

                # Publish Twist message
                twist.linear.x = linear_x
                twist.angular.z = angular_z
                pub.publish(twist)
                rospy.loginfo(f"linear.x: {linear_x:.2f}, angular.z:
{angular_z:.2f}")
           elif key is not None:
                # Any other key stops the robot
                linear_x = 0.0
                angular_z = 0.0
                twist.linear.x = 0.0
                twist.angular.z = 0.0
                pub.publish(twist)
                rospy.loginfo("Stopped")

           # Exit on CTRL-C
           if key == '\x03':
                break

           rate.sleep()

           # Ensure robot stops on exit
           twist = Twist()
```

```
    pub.publish(twist)

if _name__== '_main_':
    try:
    main()
    except rospy.ROSInterruptException:
    pass
```

3. **elbow publisher**

```
#!/usr/bin/env python3
import rospy
from geometry_msgs.msg import Twist
import sys
import select
import tty
import termios

# Instructions for user
msg = """
Control Your Robot!
---------------------------
i/, : move
forward/backward k   :
stop
t   : emergency stop (set all velocities to
0) anything else : stop

CTRL-C to quit
"""

# Key bindings
bindings = {
      'i': (1.0, 0.0),   # Forward
      ',': (-1.0, 0.0),  # Backward
      'm': (0.0, 1.0),   # Turn left
      '.': (0.0, -1.0),  # Turn right
      'u': (0.1, 0.0),   # Increase linear velocity
      'o': (-0.1, 0.0),  # Decrease linear velocity
      'j': (0.0, 0.1),   # Increase angular velocity
      'l': (0.0, -0.1),  # Decrease angular velocity
      'q': (0.1, 0.1),   # Increase speed multiplier
      'z': (-0.1, -0.1), # Decrease speed multiplier
      'k': (0.0, 0.0),   # Stop
      't': (0.0, 0.0) # Emergency stop
}

def getKey():
      # Get a single character from stdin without requiring Enter
      old_settings = termios.tcgetattr(sys.stdin)
      try:
      tty.setcbreak(sys.stdin.fileno())
```

```
    if select.select([sys.stdin], [], [], 0.1)[0]:
        return sys.stdin.read(1)
    return None
    finally:
    termios.tcsetattr(sys.stdin, termios.TCSADRAIN, old_settings)

def main():
    rospy.init_node('elbow_teleop_keyboard',
    anonymous=True)   pub   =   rospy.Publisher('/elbowVel',
    Twist, queue_size=10) rate = rospy.Rate(10) # 10 Hz

    # Initial values
    linear_x = 0.0
    angular_z = 0.0
    speed_multiplier = 1.0
    max_linear = 0.5   # Max linear velocity (m/s)
    max_angular = 1.0 # Max angular velocity (rad/s)

    # Print instructions
    print(msg)

    while not rospy.is_shutdown():
    key = getKey()
    twist = Twist()

    if key in bindings:
        linear_change, angular_change = bindings[key]

        if key in ['i', ',', 'm', '.', 'k', 't']:
            # Direct motion commands
            linear_x = linear_change * max_linear *
speed_multiplier speed_multiplier   angular_z =

                                    angular_change *

                                    max_angular * if key ==

                                    't':

                                    linear_x = 0.0
                                    angular_z =
                                    0.0
```

```
print("Emer                              Stop!")
gency
                 elif key in ['u', 'o', 'j', 'l']:
                      # Adjust base velocities
                      linear_x += linear_change * speed_multiplier
                      angular_z += angular_change * speed_multiplier
```

```
max_linear) max_angular)                linear_x = max(min(linear_x,

                                        max_linear), - angular_z =

                                        max(min(angular_z,

                                        max_angular), -

                                          elif key in ['q', 'z']:
                                               # Adjust
                                               speed
                                               multiplier
2.0))                                          speed_mult
                                               iplier +=
                                               linear_cha
                                               nge
                                               speed_multiplier = max(0.1,

                                               min(speed_multiplier,

                                               print(f"Speed multiplier:

                                               {speed_multiplier:.2f}")

           # Publish Twist message
           twist.linear.x = linear_x
           twist.angular.z = angular_z
           pub.publish(twist)
           rospy.loginfo(f"linear.x: {linear_x:.2f}, angular.z:
{angular_z:.2f}")
      elif key is not None:
           # Any other key stops the robot
           linear_x = 0.0
           angular_z = 0.0
           twist.linear.x = 0.0
           twist.angular.z = 0.0
           pub.publish(twist)
           rospy.loginfo("Stopped")

      # Exit on CTRL-C
      if key == '\x03':
           break
```

```
      rate.sleep()

      # Ensure robot stops on exit
      twist = Twist()
      pub.publish(twist)

if _name__== '_main_':
      try:
      main()
      except rospy.ROSInterruptException:
      pass
```

4. <u>imu readings subscriber:</u>

```
#!/usr/bin/env python3
import rospy

from    std_msgs.msg    import

Int32 nodeName='imuAngles'

topicNameWrist='wristAngle_m
'
topicNameElbow='elbowAngle_m
'
topicNameBase='baseAngle_m'

def cbWrist(msg1):
     print("Wrist angle: %s" %msg1.data)

def cbElbow(msg2):
     print("Elbow angle: %s" %msg2.data)

def cbBase(msg3):
     print("Base angle: %s" %msg3.data)


rospy.init_node(nodeName, anonymous=True)

rospy.Subscriber(topicNameBase,Int32,cbBase)
rospy.Subscriber(topicNameElbow,Int32,cbElbow)
rospy.Subscriber(topicNameWrist,Int32,cbWrist)

rospy.spin()
```

Assessment Guideline for Faculty

[The following assessment guideline is for faculty ONLY. **This portion is not applicable for students**.]

Assessment Tools and CO Assessment Guideline

	Distribution of assessment points among various COs assessed in different semesters

PO	l	c	f	g	c	b	d	c	e	l	k	k	h	i	j

CO	CO1	CO2	CO3	CO4	CO5	CO6	CO7	CO8	CO9	CO10	CO11	CO12	CO13	CO14	CO15
EEE 400C/ ECE 402C (Out of 100)							30	24	6	4	4	6	7	7	12
Project Final Report/ Project Progress Report							x	x	x	x	x	x	x		x
Demonstration of working prototype							x								x
Progress Presentation/ Final Presentation								x			x				
Peer-evaluation*													x	x	
Instructor's Assessment*													x	x	
Demonstration at FYDP Showcase								x							x

Note: The star (*) marked deliverables/skills will be evaluated at various stages of the project.

Mapping of CO-PO-Taxonomy Domain & Level- Delivery-Assessment Tool

Sl.	CO Description	PO	Bloom's Taxonomy Domain/Level	Assessment Tools

CO7	**Evaluate** the performance of the developed solution with respect to the given specifications, requirements and standards	d	Cognitive/ Evaluate	• Demonstration of working prototype • Project Progress Report on working prototype
CO8	**Complete** the final design and development of the solution with necessary adjustment based on performance evaluation	c	Cognitive/ Create	• Project Final Report • Final Presentation • Demonstration at FYDP Showcase
CO9	**Use** modern engineering and IT tools to design, develop and validate the solution	e	Cognitive/ Understand, Psychomotor/ Precision	• Project Final Report
CO10	**Conduct** independent research, literature survey and learning of new technologies and concepts as appropriate to design, develop and validate the solution	l	Cognitive/ Apply	• Project Final Report
CO11**	**Demonstrate** project management skill in various stages of developing the solution of engineering design project	k	Cognitive/ Apply Affective/ Valuing	• Project Final Report • Project Progress presentation at various stages
CO12	**Perform** cost-benefit and economic analysis of the solution	k	Cognitive/ Apply	• Project Final Report
CO13	**Apply** ethical considerations and professional responsibilities in designing the solution and throughout the project development phases	h	Cognitive/ Apply Affective/ Valuing	• Peer-evaluation, • Instructor's Assessment

				• Final Report
CO14**	**Perform** effectively as an individual and as a team member for successfully completion of the project	i	Affective/ Characterization	• Peer-evaluation • Instructor's Assessment

CO15**	**Communicate** effectively through writings, journals, technical reports, deliverables, presentations and verbal communication as appropriate at various stages of project development	j	Cognitive/ Understand Psychomotor/ Precision Affective/ Valuing	• Project Final Report • Progress Presentations, • Final Presentation • Demonstration at FYDP Showcase

Note: The double star (**) marked CO will be assessed at various stages of the project through indirect deliverables.