# DESIGN AND DEVELOPMENT OF AN INTERNAL PIPE INSPECTION ROBOT

A Final Year Project Report

Presented to


**SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING**

Department of Mechanical
Engineering
NUST
ISLAMABAD, PAKISTAN


In Partial Fulfillment

of the Requirements for the Degree of
Bachelor of Mechanical Engineering

by


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# ABSTRACT

Pipelines are an integral part of the infrastructure, whether it be in Oil and Gas, Municipality or any other industry. The pipe network has increased over the past years, and increased usage has led to issues in pipelines such as corrosion, pitting, leaks etc. Such issues in the piping network can result in the loss of transported materials and leaks, which can negatively impact the environment.

Thus, it is important to regularly inspect these pipelines, which usually requires significant manpower. However, conditions might expose humans to hazardous substances, confined spaces and many other risks, and may even present a case where a pipeline section is inaccessible to direct human access.

Many major companies already have robots to provide services for clients, and the industry is estimated to be worth 4 billion dollars by 2028. [1] Thus, it is important to develop In Pipe Inspection Robots indigenously.

Literature review showcased that the in-pipe inspection robots are classified majorly on their propulsion types – wheel driven, tracked, PIG, Screw Driven, Legged, Inch Worm or Snake robots. Keeping in view complexity and costs, we opted for a 6 linked robot propelled by 3 driving wheels and 3 wheels for support.

Initial testing of our final design showed promising results in achieving the objectives we had aimed for, and the design successfully adapted to changing pipe diameters, transversed smooth curves ($45^{o}$) and also traveled in vertical pipelines.

Further improvements on the prototype are possible, such as integrating an ML algorithm for pipe inspection, further mechanical modifications to meet requirements (such as remote operations through Wi-Fi/Bluetooth).

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# INTRODUCTION

## Problem Statement

Pipeline maintenance and inspection in different industries is essential for ensuring infrastructure integrity and safety. Traditional methods are usually employed to achieve this task, which usually involve manpower. However, conditions might expose humans to hazardous substances, confined spaces and many other risks, not to mention efficiency and cost-effectiveness.

Thus, a need for a more reliable and advanced solution arises, promoting the development of inspection robots that travel internally of pipes. These robots can be designed to autonomously navigate pipelines, provide vital data with respect to the internal health of the pipeline and detect issues such as leaks, corrosion, structural defects etc.

There are many requirements of such a robot, such as:

1. Navigation in closed and confined spaces
2. Ability to integrate sensors on the robot platform
3. Reliably communicate data transfer
4. Robustness and power availability
5. Adapt to changing pipe environment (bends, incline, vertical etc.

## Objectives

The objectives of the Design and Development of Internal Pipeline Inspection (IPI) Robot are as follows:

1. Design and manufacturing of IPI's main body
2. Remotely Controlling IPI, increasing safety and access of humans
3. Data Acquirement from IPI's sensors/camera
4. Maneuverability in a variety of pipeline environments (such as changing diameter, inclined, bends etc.)
5. Increasing pipe inspection efficiency
6. Increased longevity and robustness by using materials that can withstand forces and the general pipeline environment
7. Compatibility and integration in the future when required, ensuring future modifications that can improve IPI's requirements.

## Motivation

Backed by a comprehensive understanding of engineering fundamentals, command over essential software, and insights garnered from various internships within the industrial domain, the members of our group aimed to integrate diverse disciplines into our Final Year Project (FYP). Our objective was to create an innovative engineering solution capable of addressing real-world challenges, thereby potentially influencing large-scale outcomes. Motivated by this goal, our group engaged in extensive brainstorming sessions to generate creative ideas for potential innovations, which could subsequently be proposed to our department.

The collective preference within our group leaned towards integrating robotics and automation alongside control systems. We also recognized the importance of mechanical design as an essential component of any viable solution. Drawing from our past experiences, particularly in projects involving the design and implementation of microcontroller-based control systems, we felt confident in applying similar principles on a larger scale.

Regarding potential sectors for project positioning, the municipality and oil and gas sectors emerged as compelling choices for two primary reasons. Firstly, the aging pipeline infrastructure in major cities in Pakistan holds immense significance, presenting a critical area where our project could have a substantial impact. Secondly, despite the pressing need, the sector has witnessed limited technological advancements and innovation in recent times, thus presenting a notable opportunity for us to propose a solution capable of catalyzing progress in this critical sector.

Our group's approach involved thorough research and a detailed analysis of the challenges faced by these sectors. We focused on identifying gaps where our engineering solution could be most effective, leveraging our collective expertise to develop a project proposal that was both innovative and practical. Through this process, we aimed to create a solution that not only addressed existing issues but also introduced new possibilities for technological advancement and efficiency.

1. Aging Infrastructure: Pakistan's pipeline network, particularly in the oil and gas sector, is aging and requires regular inspection and maintenance to ensure its integrity and reliability. Internal pipeline inspection robots can efficiently

navigate through these pipelines, identifying corrosion, leaks, and other defects that may compromise their structural integrity.

2. Geographic Diversity: Pakistan's diverse geography, including rugged mountainous terrain, desert regions, and coastal areas, presents unique challenges for pipeline maintenance and inspection. Internal pipeline inspection robots can access remote and challenging locations, providing comprehensive coverage of the pipeline network across diverse landscapes.
3. Safety Concerns: Traditional methods of pipeline inspection often involve human entry into hazardous environments, posing risks to personnel. In Pakistan, where safety standards may vary and enforcement can be challenging, internal pipeline inspection robots offer a safer alternative by minimizing human exposure to dangerous conditions such as high-pressure environments, toxic gasses, and confined spaces.
4. Environmental Protection: Leakages or failures in pipelines can have severe environmental consequences, including contamination of soil, water sources, and ecosystems. Internal pipeline inspection robots can help mitigate these risks by detecting leaks and defects early, minimizing the potential for environmental damage, and ensuring compliance with environmental regulations.
5. Efficiency and Cost Savings: Manual inspection of pipelines can be time-consuming, labor-intensive, and costly. Internal pipeline inspection robots offer a more efficient and cost-effective alternative by automating the inspection process, reducing the need for manual labor, and minimizing downtime associated with traditional inspection methods.

# LITERATURE REVIEW

The literature review focused on the development, design and fabrication of a robot that could navigate in pipelines and provide a platform for sensors and different electronics needed to identify issues within pipelines

## Classification of In-Pipe Inspection Robots

Pipeline Inspection Robots have two primary classifications - external and internal pipeline inspection robots. External Pipeline Inspection Robots primarily inspect the outside of pipes, providing limited insight to the internal pipeline health and conditions. Internal Pipeline Inspection Robots on the other hand, Inspect the robot internally. This provides a convenient solution to inspect pipelines, since it can provide detailed information about the inside of the pipeline, even in environments which are inaccessible from the outside (buried pipes etc.).

Internal Pipeline Inspection Robots can be further divided into the following categories:

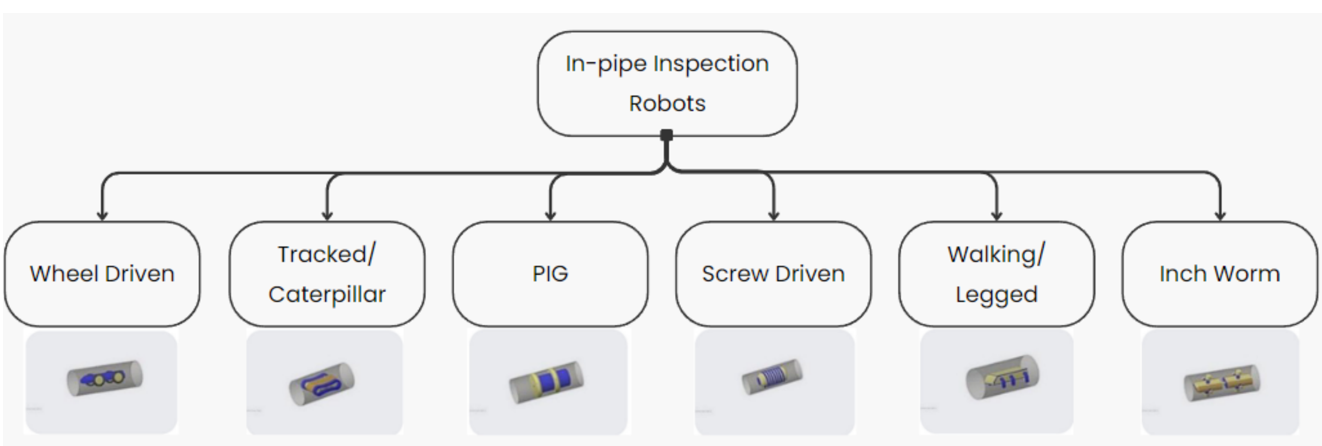



*Figure 1 Types of different Internal Pipeline Inspection Robots*

### Wheel Driven Robots

Robots with wheels are the most common category, employed by a variety of companies providing pipe inspection services. The robot is propelled by its wheels, which are driven by gear motors or actuators. The majority of wheel-driven robots are equipped with adaptation systems that allow their wheels to keep traction throughout their movement. [1]This is particularly important if the robot has to climb any vertical pipes. Another kind of wheel-drive in-pipe robot is basic and made solely for horizontal motion; as a result, its arms are not adjustable. [2]

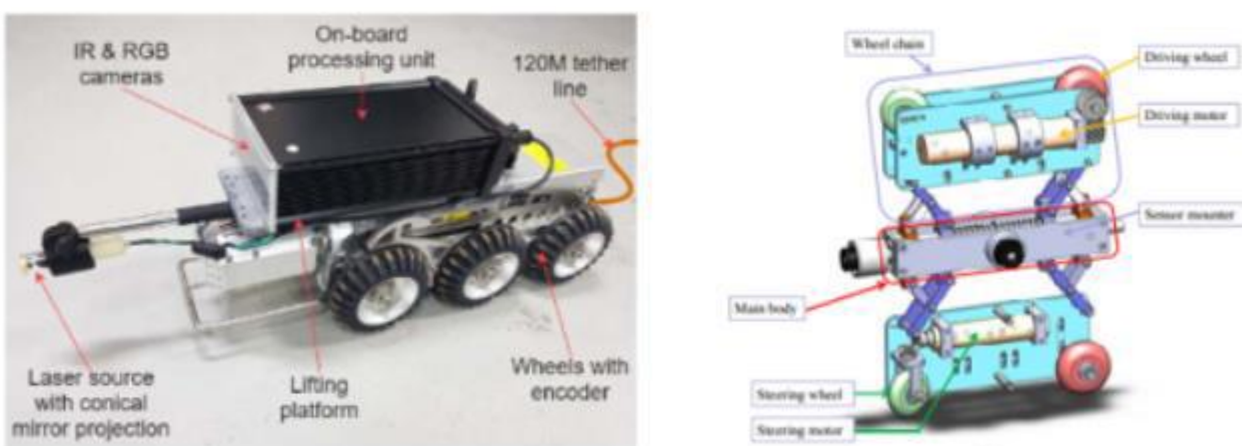



*Figure 2 Examples of wheeled robots*

Another classification in this category also depends on the number of wheels being employed by the robot, which can be two, three, or six. All these wheels are uniformly spaced around its central axis, ensuring balanced movement and stability. Wheeled robots are favored in many applications due to their ease of movement, cost-effectiveness, and straightforward design. They can efficiently navigate various terrains and are typically simpler to control compared to other types of robots. The uniform spacing of the wheels not only enhances stability but also allows for smoother and more predictable maneuverability. Additionally, the economic advantage and mechanical simplicity of wheeled robots make them an attractive option for many robotics projects, from basic educational kits to advanced industrial applications.

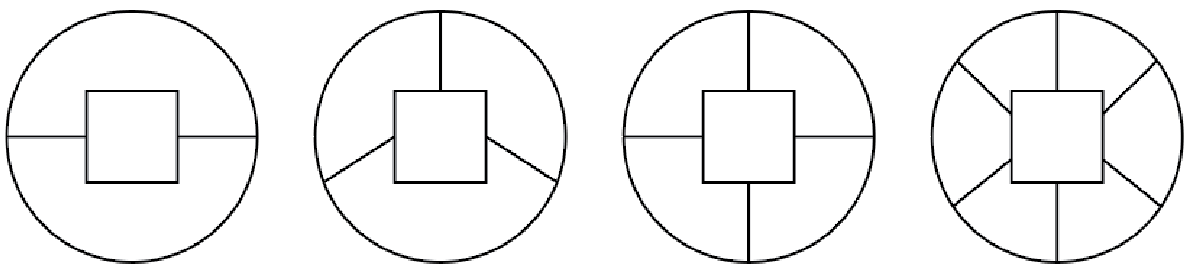


*Figure 3 Types of In-pipe Inspection Robots Motion*

### Tracked Robots

Robots can also be propelled by rails rather than wheels, offering a different set of advantages. Caterpillar track robots, for instance, provide excellent traction force and stability. These robots are designed to carry not only their own body weight but also bulky equipment, making them suitable for heavy-duty tasks. The three main components of such a robot are the pantograph mechanism, the caterpillar wheel track, and the core body.

The pantograph mechanism ensures the robot's movements are precise and stable, adjusting the height and angle as needed. This mechanism is crucial for maintaining balance and adapting to various operational requirements. The caterpillar tracks, similar to those used in tanks, distribute the robot's weight evenly across the surface, enhancing grip and minimizing slippage on various terrains. These tracks allow the robot to traverse uneven and rugged landscapes with ease, making them ideal for outdoor and industrial environments. The core body houses the essential electronics, power supply, and control systems, ensuring the robot operates efficiently and effectively. This central unit integrates all necessary components, from sensors to processors, allowing for seamless communication and control. Together, these components make caterpillar track robots a reliable choice for tasks requiring robust performance and the ability to handle challenging environments.

Nonetheless, the robots have other difficulties, such as limited mobility and sluggish speed. [3]

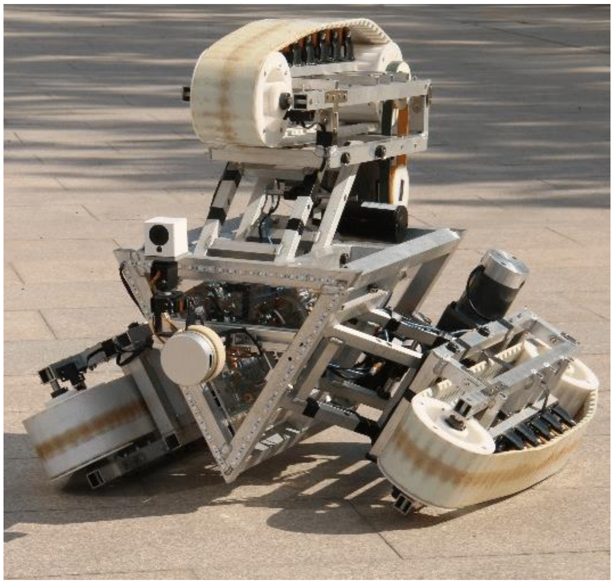


*Figure 4 An example of a tracked robot*

## Pipe Inspection Gauge (PIG) Robot

One of the most widely used inspection robots for cross-country pipelines is the PIG-type robot. This type of robot is essential for cleaning pipelines or checking their condition. However, a major drawback of PIG-type robots is that they are typically designed to work with only a single pipe diameter, limiting their versatility. These robots travel through pipelines using the fluid velocity within the pipe.

Numerous sensors on the PIG-type robot gather critical data, including orientation, velocity, vibration, temperature, position, and internal pipe diameter. This comprehensive data collection helps in assessing the pipeline's condition accurately. The robot is equipped with an integrated battery and data storage unit, as it operates wirelessly. Data collected by the robot is retrieved after the PIG is received at the end of its inspection journey.

However, one significant limitation of most PIG-type robots is the lack of actuators. This absence complicates complex movements and restricts the robot's ability to navigate obstacles or adjust during inspection. Actuators could enhance the robot’s maneuverability and adaptability, allowing it to perform more intricate tasks and navigate through varying pipe conditions more effectively. [4]

*Figure 5 A pipe inspection gauge robot*

## Screw Drive Robots

Considered an advanced version of wheeled robots, screw-type robots utilize a helical drive motion. These robots consist of three main components: the arm link for the wheel chain, the drive module, and the rotor. The robot's circular motion is controlled by the angle at which its front wheels are tilted, enabling it to move both rotationally and translationally during driving.

One of the significant advantages of screw-type robots is their efficiency. They require fewer actuators, making them lighter and reducing power consumption. Additionally, their simpler design translates to lower production and maintenance costs. This efficiency makes screw-type robots suitable for various applications where energy conservation and minimal upkeep are crucial.

However, screw-type robots do have limitations. One notable drawback is their inability to move backward, presenting a challenge in scenarios where reversing is necessary. Furthermore, they struggle to navigate around joints or tight corners, limiting their maneuverability in complex environments. [5]

*Figure 6 A screw drive robot*

**Legged Robots**

The walking legs of the legged/walking-type robot have many degrees of freedom (DOF), providing them with the ability to overcome various challenges when traveling. This capability is especially advantageous for inspecting sewers, as these robots can navigate tight spaces and move around bodies of water without requiring much room.

However, the design of legged robots presents several challenges. Each leg's movement is enabled by multiple actuators, resulting in a bulkier system. The complexities of designing such robots include dealing with inverse kinematics, system controllers, sequence planning, and trajectory generation. These elements are crucial for ensuring precise and coordinated movements.

Additionally, while the legs offer flexibility and maneuverability, they also present some drawbacks. The smaller surface area for traction can make it difficult for the robot to maintain stability and grip on various surfaces. Despite these challenges, the advantages of legged robots, such as their ability to traverse complex terrains and access restricted areas, make them valuable tools for specific inspection and maintenance tasks. [6]

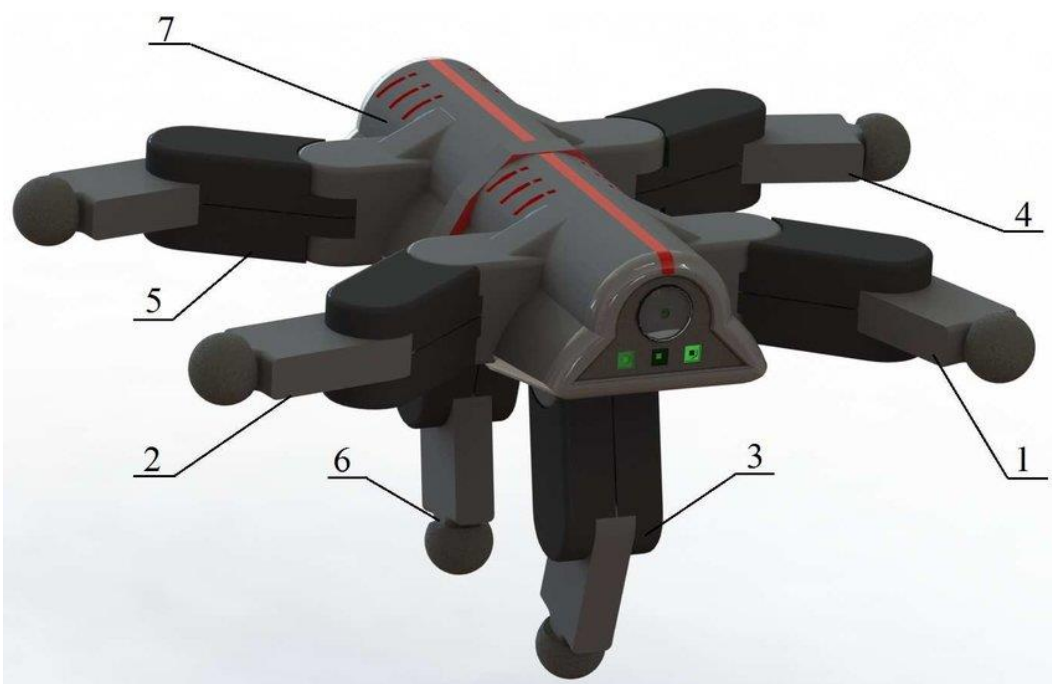



*Figure 7 A robot that is propelled by its legged mechanism*

**Inch Worm Robots**

Inch Worm Robots, inspired by the movement of earthworms, exhibit a unique locomotion mechanism. They are propelled forward through a repetitive contraction and expansion motion, mimicking the way an earthworm moves. This bio-inspired design allows them to navigate through narrow and constrained environments effectively.

Despite their innovative design, inch worm robots face some limitations. Their driving speeds are generally slow, which can be a drawback in applications requiring rapid movement. Additionally, the repetitive motion generates considerable friction, which can impact the robot's efficiency and potentially cause wear over time. Despite these challenges, inch worm robots remain valuable for specific tasks that benefit from their ability to maneuver through tight spaces and their adaptable, bio-inspired movement. [7]

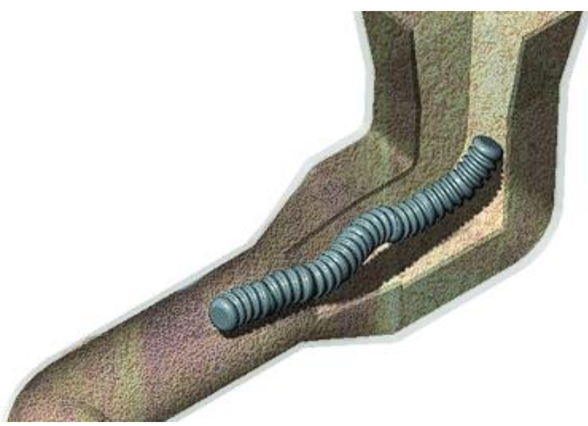


*Figure 8 A robot that propels itself through movement similar to an inch worm*

# METHODOLOGY

## Initial Design

While reviewing literature, we encountered a variety of designs, most of which were wheel and tracked robots. However, many of these designs had significant drawbacks, such as being too bulky to traverse through inclined pipelines or being costly to manufacture.

In selecting our design, we considered several crucial factors: weight, maneuverability, power efficiency, and size. Our goal was to create a solution that could address the limitations of existing designs while optimizing performance for our specific application.

The design process is outlined as follows:

1. **Requirement Analysis**: Identifying the key requirements for the robot, including the need to navigate inclined pipelines, manage power efficiently, and maintain a compact size.

2. **Conceptual Design:** Generating initial design concepts that balance weight and maneuverability, ensuring that the robot could perform well in the intended environment.

3. **Prototype Development:** Building a prototype based on the selected design concepts, incorporating features to address issues identified in the literature review.

4. **Testing and Iteration:** Evaluating the prototype's performance in real-world conditions and iterating the design based on feedback and performance metrics to refine and enhance functionality.

5. **Final Design:** Finalizing the design with improvements and adjustments made during testing, ensuring the robot meets all required criteria for weight, maneuverability, power efficiency, and size.

By focusing on these aspects, we aimed to develop a more effective and practical solution for traversing inclined pipelines, overcoming the limitations of previous designs.

**Concept 1**

The figure below shows the first design we came up with but after evaluations, we rejected the design due to the following reason

1: The design involved complexities that could be easily avoided. Secondly, the body weight was becoming too much, and it meant extra strain on the motor and limited ability to move in inclined pipes

2: The motor required for such a massive body was of a very high rating and the cost alone was out of budget of this project

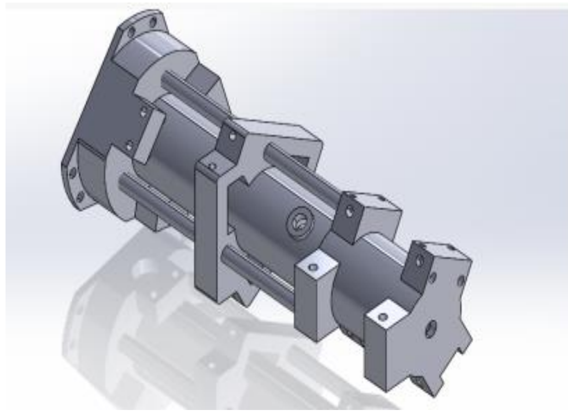


*Figure 9 The main body of the initial concept*

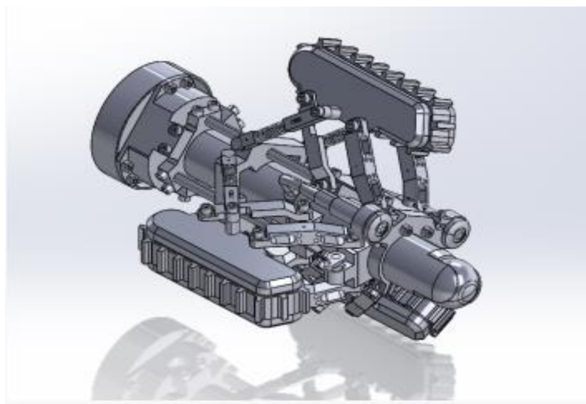


*Figure 10 Fully Designed robot with tracks*

Due to the following reasons, we brainstormed a simpler design where the body did not take up the majority of the space and weight.

**Concept 2**

Design 2 was developed to address the shortcomings of the first design. In this iteration, we streamlined the body to use the minimum amount of material required, incorporating bars to provide necessary structural support and weight. This approach helped reduce bulk and enhance the robot's maneuverability.

Additionally, instead of the previous power screw and stepper motor arrangement, we integrated an electric putter to control the opening and closing configurations of the tracks. This modification aimed to simplify the mechanism, improve efficiency, and reduce overall system complexity. By implementing these changes, Design 2 became more effective for its intended application, offering better performance and reliability in navigating inclined pipelines and other challenging environments.

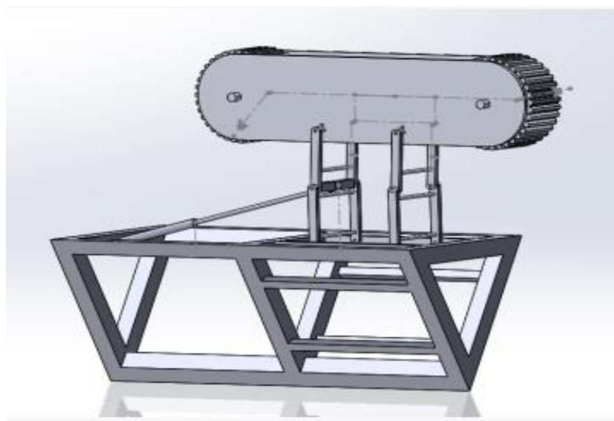


*Figure 11 Redesign of the initial robot*

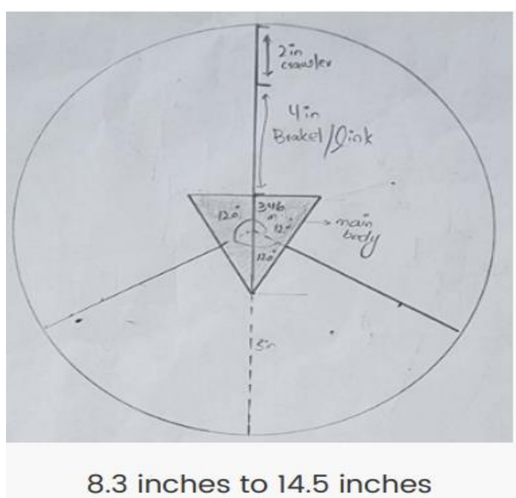



*Figure 12 Working on the maximum and minimum diameter pipe that the robot could transverse*

However, Design 2 encountered its own set of issues:

1. **Electric Putters for Each Track**: The use of electric putters for each track introduced additional power consumption and weight, which were not ideal. This increased the overall complexity and energy requirements of the system.

2. **Additional Weight from Tracks**: The tracks themselves added extra weight to the robot. Coupled with the electric putters, this precluded the use of a wheel design, which could have been more efficient and lighter.

These challenges highlighted the need for further refinement to balance the trade-offs between functionality, weight, and power efficiency in the design.

**Concept 3**

After further deliberation and development, our team arrived at the final design for the IPI robot. This design effectively addresses the issues of additional weight caused by electric putters and tracks, as well as the body weight problems encountered in Design 1.

The final design integrates a single stepper motor and power screw arrangement to control the diameter of the IPI. This approach helps streamline the system, reducing overall weight and complexity while maintaining effective control over the robot's size and functionality. By incorporating these changes, we aimed to create a more efficient and practical solution for the intended application.

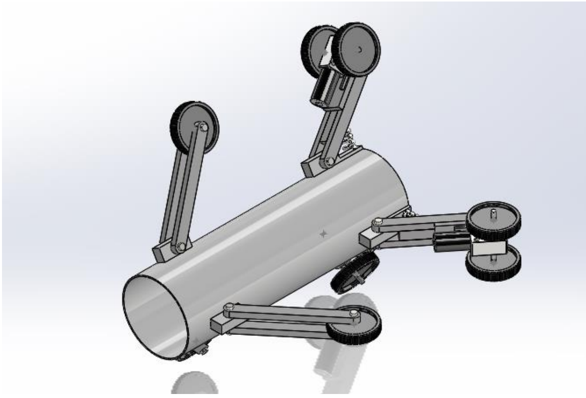


*Figure 13 Finalized Design of IPI robot*

*Figure 14 Final Developed model of IPI*

The robot presents several advantages over the previous designs under consideration:

1. **Maneuverability:** The compact nature of our robot enables it to traverse pipe diameters ranging from 180mm to 320mm, offering a significantly larger range compared to other models developed.
2. **Redundancy:** Our robot is designed to maintain mobility even if one of its wheels fails. However, this redundancy is limited if the failed wheel is a driving wheel, as this can severely impact the robot's ability to make vertical turns.
3. **Flexibility:** The support wheels on the IPI help keep the robot centered and guide it through turns and changes in pipe diameter, enhancing its overall

maneuverability.

4. **Stability:** With more wheels in contact with the pipe walls, the robot's stability is improved, especially on pitted surfaces and bumps. This design feature reduces the risk of slippage and helps prevent the robot from falling.
5. **Cost:** The simple design, combined with relatively inexpensive 3D printing, allows the robot to be manufactured at a fraction of the cost compared to more complex designs. Additionally, the use of lightweight and robust materials means that the motors required for propulsion are also relatively cheaper.

These advantages make our robot a more effective and cost-efficient solution for traversing and inspecting pipelines.

**Main Body**

The main body is circular in design, with a diameter of 59mm, and a thickness of 2mm. The body used was an old PVC pipe. A PVC pipe was selected due to costs and simplicity. Metal alloys were not used keeping in view weight consideration and again, costs. Furthermore, a PLC 3D print would have also been costly for something available off the shelf and a fraction of the price (Prices Appendix I).

On the main body, acrylic was used to create the base to which the links would be attached using screw (stress analysis was done and vigorous testing was done to ensure it does not break/fail). The acrylic was attached to the main body using screws.

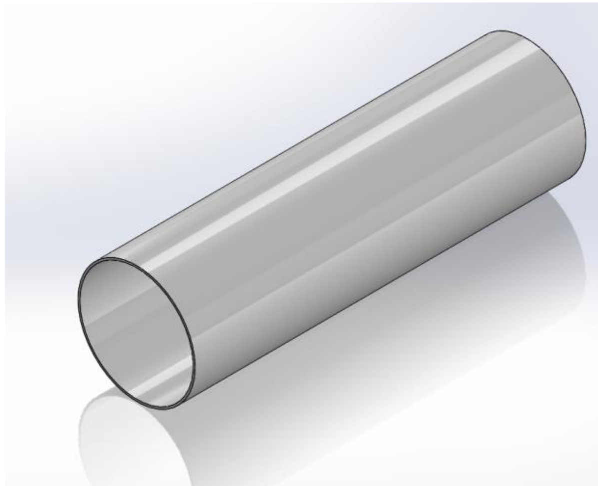


*Figure 15 Main Body of IPI*

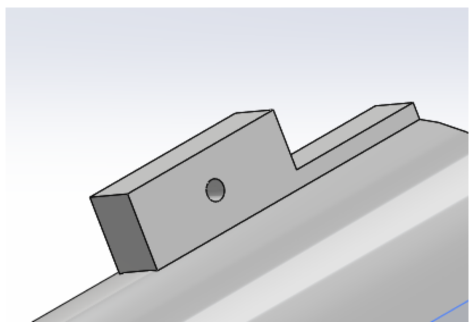


*Figure 16 The addition to the main body to attach links*

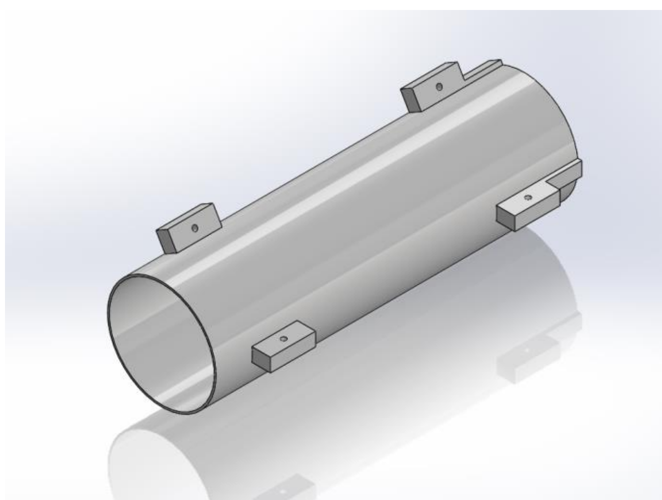


*Figure 17 Full body of IPI*

**Links and Wheels**

For the links, we used PLC printing to get the desired dimensions and weight. Stress analysis was done and also physical experiments were done to ensure that the links do not fail during operations.

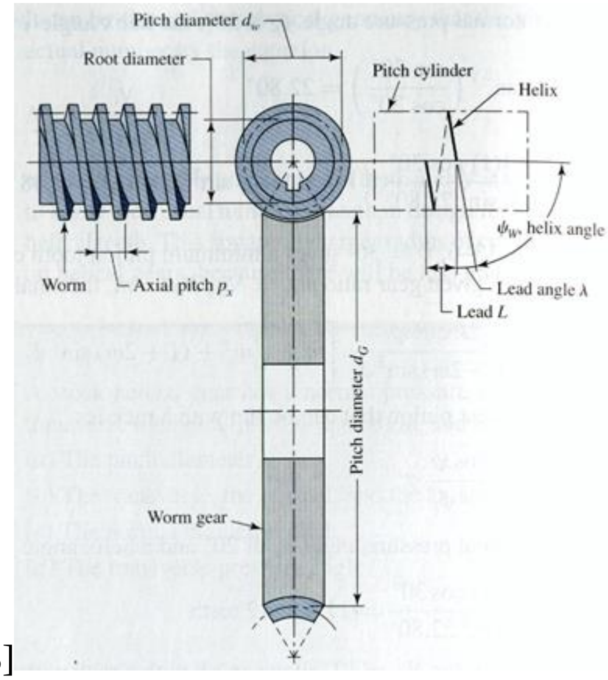
Furthermore, for the driven wheels, off the shelf wheels. However, acrylic wheels of custom diameter were used for the driving wheels, along with a rubber attached to its diameter for traction.

Although a helical spring was initially planned to provide the force outwards on the walls, the placement was becoming a bit tedious. The torsional spring was added by iterations and experimentation, and a method of trial and error was adopted to choose one with the right spring constant and length for both the front and back wheels.

The DC gear motor was selected after a hit and trial approach, providing enough torque to support the weight of the robot in vertical pipelines.

https://sciencestore.pk/product/dc-gear-motor-12v-24v/

The worm gear had an axial pitch $p_s$ of 0.10mm, a root diameter of 10mm, and the worm wheel had a diameter of 15 mm, with 60 teeth.




[8]

*Figure 18 The different parameters involved in a worm and gear mechanism*

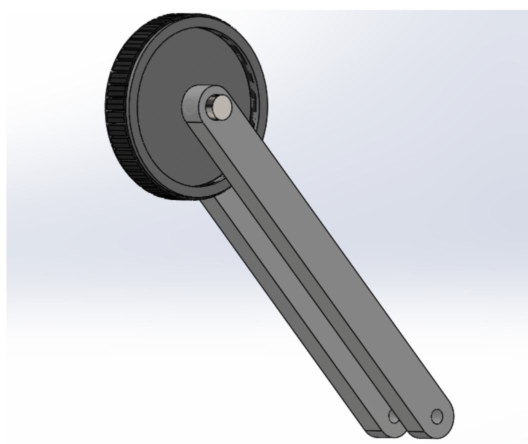


*Figure 19 Design of the support/driven wheel of IPI*

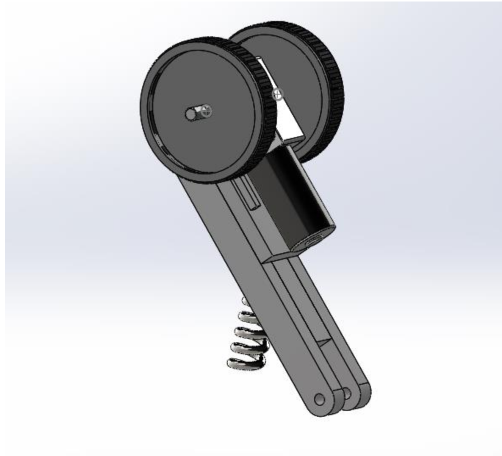


*Figure 20 Design of IPI's driving wheels*

*Figure 21 Manufactured Driving wheel of IPI*

*Figure 22 The manufactured Driven wheels of IPI*

## Assembly

The final assembly was designed to be as follows, with springs providing the force, pushing the wheels outwards to create contact with the pipeline walls.

A power screw and motor will be used to adjust the driving wheels when required to reduce the diameter of IPI. A base plate was designed to attach to the nut on the power screw in such a manner that it moved up and down along with the nut.

Steel wires were used to connect the driving wheel links and the plate. PLC printed links were at first suggested but due to their size, were discarded and steel wires were used.

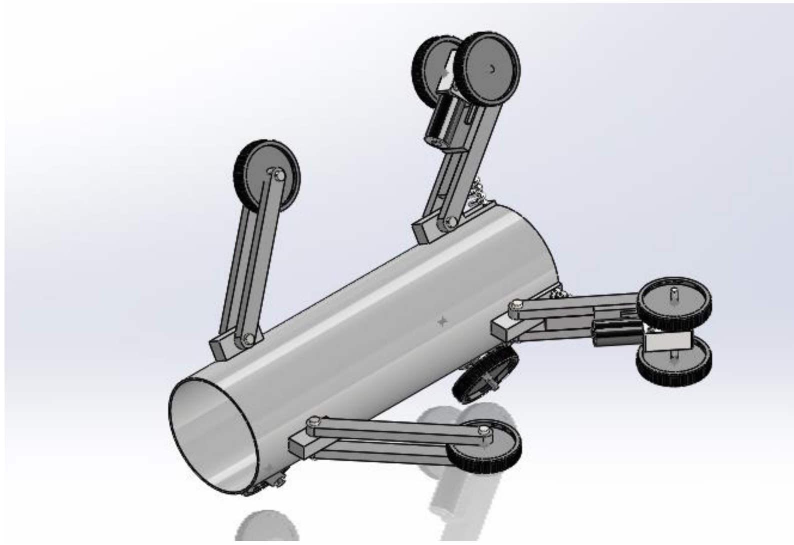


*Figure 23 Final Proposed Design of IPI*

## Calculations

## Internal Force on the walls

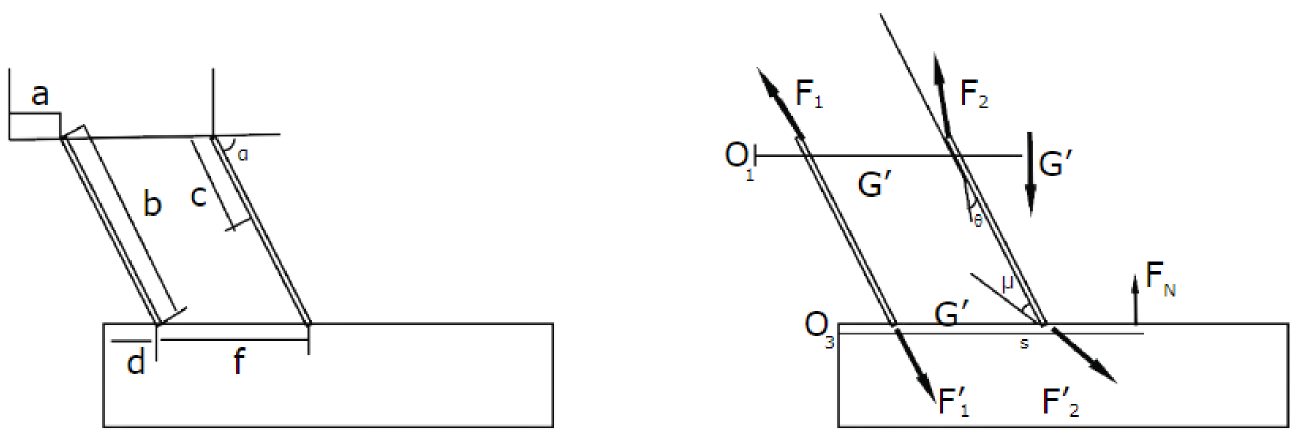



*Figure 24 Force Calculations of IPI internally on the walls*

Compared to 3 wheeled robots, our 6 wheeled pipeline inspection robot has a more stable configuration and also a more guided approach (due to the driven wheels which provide support). The links and the body were simplified into the below diagram, and forces adjusted accordingly.

a, b, c, d, f are the external dimensions of the robot and α is the angle between the back wheels and the pipe wall.

$$F_1\ sin\ sin\ \alpha\ + F_2\ sin\ sin\ (\alpha + \theta) = G'$$

$$F_1\ cos\ cos\ \alpha\ =\ F_2\ cos\ cos\ (\alpha + \theta)$$

$$a \cdot F_1\ sin\ sin\ \alpha\ + (a + f) \cdot F_2\ sin\ sin\ (\alpha + \theta)\ \ = G'j$$

where θ is the angle between $F_2$ and the link, $G'$ is central body's gravity on the surface, j is the distance from $O_1$ to $G'$. Hence, we get the equations of forces acting on the wheels:

$$F_1' sin\ \ \alpha + F_2' sin\ (\alpha - \mu) = F_N$$

$$d \cdot F_1' sin\ \ \alpha + (d + f) F_2' sin\ (\alpha - \mu) = F_N \cdot s$$

$F_N$ = equivalent force acting on the links, s = distance from $O_3$.

Putting in the dimensions of the robot, the equation becomes easily solvable.

$F_a$, $F_b$ and $F_c$ are denoting friction. Assuming that the weight of the robot is in the center and force is provided by the pipe wall, we can simplify the model into the following equation when the robot is moving in an upright position in a stable pipe (figure attached for reference):

$$F_a + mg = (F_b + F_c)cos\ 60$$

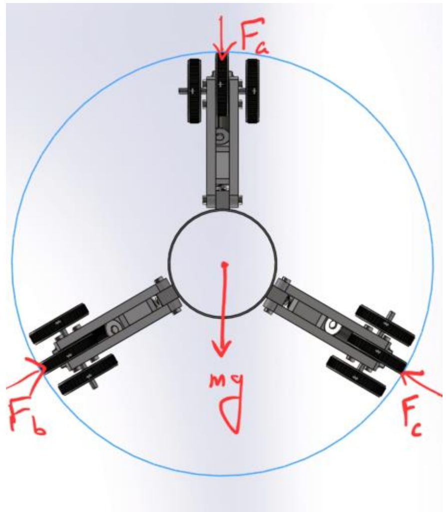



*Figure 25 Force of IPI on the walls and due to gravity*

## Stress Analysis

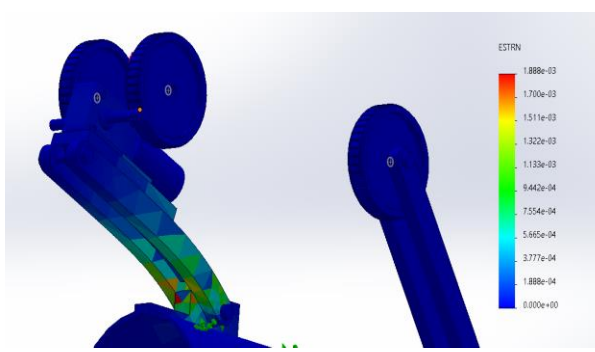



*Figure 26 Strain in IPI's links*

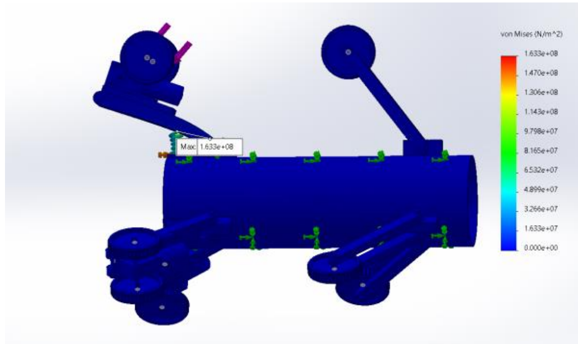



*Figure 27 Strain Calculations of IPI due to 20N force*

The IPI Robot does not have to bear high loads, and the maximum force/load is present on the linkages (force on the wheels). For our calculations, we considered a force of 20N and took the worst-case scenario where the linkage screw gets stuck (bending occurs in the linkage).

As can be seen in the diagram (a force of 20N), the maximum stress developed is in the spring which is of a magnitude of 163 MPa. Hence, in material selection, we were able to use a steel alloy with a yield stress of 500 MPa.

The maximum stress develops in the PLC Linkages, which is $1.83*10^{-3}$ which is under the maximum limit allowed for PLC.

Thus, from our calculations, we were able to deduce that no failure would occur and that our design was good to manufacture. Once manufactured, rigorous testing proved our initial calculations, and IPI was successful in achieving its objectives.

## Control System

The project at first aimed to attach the microcontroller to the body of IPI along

with Lithium Ion batteries, but due to the extra weight, it was decided against and a wired configuration of the robot was opted for.
An Arduino Nano was chosen as the microcontroller. JDY-S31 Bluetooth module was used to relay commands to the Arduino, which further related commands to the motors, camera, lighting and so on as per requirements. Regulators were used to keep voltage levels according to the required amount (since the Arduino Nano can sustain a maximum of 5V but the motors required up to 24V).
The motor driving the wheels was selected by a hit and trial method due to the available motors in the market. [9]

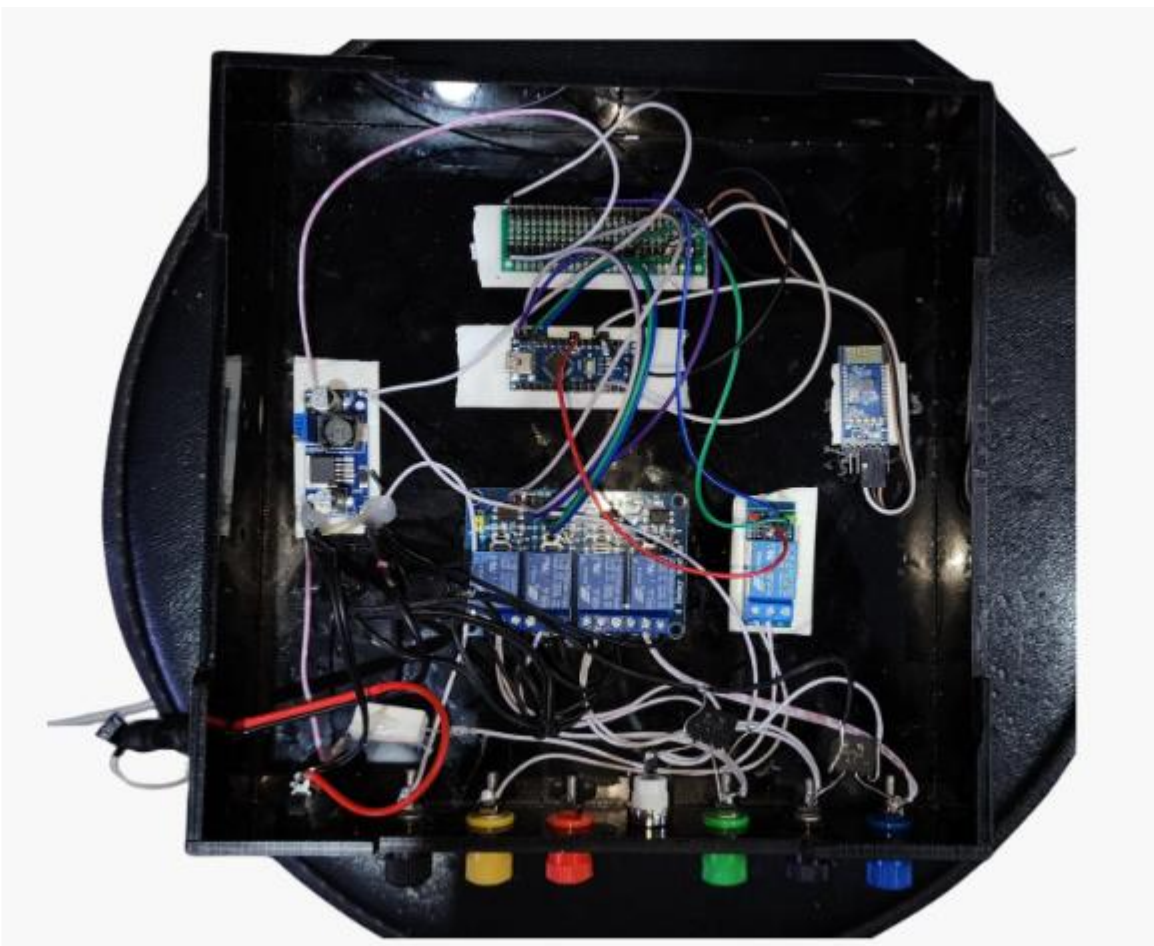


*Figure 28 Electric Configuration of the control box of IPI*

Furthermore, App Inventor MIT [10] was used to develop an app so that IPI can be controlled from mobile phones. The phone directly communicated with JDY S31, and the arduino code uploaded to the Nano (attached as APPENDIX I) controlled the functions of the robot.


*Figure 29 App Interface Developed through MIT App Inventor*

## RESULTS AND CONCLUSIONS

Through the use of a proven design of 6 wheeled rover design with diameter control by a power screw mechanism, along with the addition of springs and powering only 3 wheels instead of the usual 6 (to save on weight), the internal pipeline inspection (IPI) robot provides utility and cost saving.

The design was finalized after lengthy review of existing literature to reach a viable design, and three designs were proposed but rejected due to feasibility such as costs or availability of parts and manufacturing. The group was able to achieve the objectives outlined at the start of the project, successfully achieving all four of them.

The principles utilized throughout the design process focused on maneuverability, adaptability, ease of use and reliability.

The Robot was successfully able to transverse pipelines of varying diameters between 205mm to 300m. It was also able to successfully maneuver in a 45$^{o}$ bend in both the horizontal and vertical pipe configurations.

| | |
|---|---|
| Adaptive Diameter | 205 - 300 mm (dia) |
| Axial Length | 210 mm |
| Maximum Speed | 0.28 m/s |
| Total Weight | 1.0 kg |

*Table 0.1 Parameters of IPI*

*Figure 30 Final Construction of IPI*

**Future Recommendations**

Owing to the modular design and cost restrictions, there is a lot of potential to develop IPI further, upgrading it as per requirements. Some of these suggestions are as follows:

1. Improved Casing: IPI could have a dedicated PLC made casing, encapsulating all the open wires and springs. This is a costly upgrade but will greatly increase the robustness of IPI and allow it to withstand more rigorous environment testing.
2. Upgraded Sensors: IPI's body provides ample space for additional sensor additions, as per requirements of the pipeline being inspected. Additional Sensors can be easily integrated and the Arduino Nano used can be upgraded to an Arduino Uno or Mega according to the capacity of sensors and processing requirements. This will allow for inspection as per different requirements.
3. Integration of an ML Model: An ML model can be trained so as to detect different defects inside pipelines as per requirements. Due to unavailability of necessary data and the lack of domain knowledge, this was not an objective that

our team aimed for at the start of the project but are confident will be an important addition to IPI's platform.

4. Improved App Experience: The control box can be integrated with a screen and the app functionalities can be shifted directly to the modular box, allowing for a better interface and control experience. Joysticks can be added for the movements, creating a more natural control of the rover.
5. Varying voltage to motors: Voltages can be varied to each motor driving the wheels. This can allow for rotation (one wheel slows, the faster wheel moves forward, creating a rotational motion) which can increase maneuverability and provide greater control to the operators.

# REFRENCES


[1] "https://ieeexplore.ieee.org/document/9270040," IEEE, - - -. [Online]. Available: https://ieeexplore.ieee.org/document/9270040. [Accessed 02 05 2024].

[2] "https://ieeexplore.ieee.org/document/5979712," IEEE, - - -. [Online]. Available: https://ieeexplore.ieee.org/document/5979712. [Accessed 02 05 2024].

[3] "Zhao, Wentao & Zhang, Liang & Kim, Jongwon. (2020). Design and Analysis of Independently Adjustable Large In-Pipe Robot for Long-Distance Pipeline. Applied Sciences. 10. 3637. 10.3390/app10103637".

[4] "John, Binil & Shafeek, M. (2022). Pipe inspection robots: a review. IOP Conference Series: Materials Science and Engineering. 1272. 012016. 10.1088/1757-899X/1272/1/012016.".

[5] "Kakogawa, Atsushi & Ma, Shugen. (2019). Robotic Search and Rescue through In-Pipe Movement. 10.5772/intechopen.88414.".

[6] "Savin, Sergei & Ludmila, Vorochaeva. (2017). Footstep planning for a six-legged in-pipe robot moving in spatially curved pipes. 1-6. 10.1109/SIBCON.2017.7998581.".

[7] "Takagi, Minoru & Yoshida, Kazunari & Hoshino, Hiroyuki & Tadakuma, Riichiro & Suzuri, Yoshiyuki & Furukawa, Hidemitsu. (2019). Sliding Walk With Friction Control of Double-Network Gel on Feet of Inchworm Robot. Frontiers in Mechanical Engineering. 5. 44.".

[8] [Online]. Available: https://www.engineersedge.com/gears/worm_gear_sizing_calculator_13819.htm.

[9] [Online]. Available: https://sciencestore.pk/product/dc-gear-motor-12v-24v/.

[10] [Online]. Available: https://appinventor.mit.edu/.

# APPENDIX I

```
char bt = 0;

int lpwm = 255;

int rpwm = 255;

#include <SoftwareSerial.h>

int enA =6;// SPEED CONT

int  in1 = 9;

int in2 = 10;

// Motor B connections

int enB =4 ;// SPEED CONT

int in3 = 11;

int in4 = 12;

SoftwareSerial mySerial(2, 3); // RX, TX

int LIGHT = 5;

void setup() {
```

```
  Serial.begin(9600);
  mySerial.begin(9600);
  pinMode(enA, OUTPUT);
  pinMode(enB, OUTPUT);
  pinMode(in1, OUTPUT);
  pinMode(in2, OUTPUT);
  pinMode(in3, OUTPUT);
  pinMode(in4, OUTPUT);
  pinMode(LIGHT, OUTPUT);

  analogWrite(enA, lpwm);
  analogWrite(enB, rpwm);
  digitalWrite(in1, HIGH);
  digitalWrite(in2, HIGH);
  digitalWrite(in3, HIGH);
  digitalWrite(in4, HIGH);
  digitalWrite(LIGHT, HIGH);
}
```

```
void loop() {
  while (mySerial.available()) {


    char bt = (char)mySerial.read();
    Serial.println(bt);
  if ( bt  == 'X')
    {
       digitalWrite(LIGHT, LOW);
    }

  if ( bt  == 'Y')
    {
    digitalWrite(LIGHT, HIGH);
    }



    if ( bt  == 'l')
    {
      forward();
    }
```

```
  if (bt == 'm')
  {
    backward();
  }

  if (bt == 'n')
  {
    MOTORU();
  }

  if (bt == 'o')
  {
    MOTORD();
  }
  if (bt == 's')
  {
    stop_robot();
  }
}
```

```
}

void forward() {

  digitalWrite(in1, HIGH);

  digitalWrite(in2, LOW);


}



void backward() {


  digitalWrite(in1, LOW);

  digitalWrite(in2, HIGH);




}




void MOTORU() {


  digitalWrite(in3, LOW);
```

```
  digitalWrite(in4, HIGH);

  delay(1000);

  digitalWrite(in3, HIGH);

  digitalWrite(in4, HIGH);


}


void MOTORD() {


  digitalWrite(in3, HIGH);

  digitalWrite(in4, LOW);

  delay(1000);

  digitalWrite(in3, HIGH);

  digitalWrite(in4, HIGH);

}


void stop_robot() {

  digitalWrite(in1, HIGH);

  digitalWrite(in2, HIGH);
```