Pipeline inspection robot

Final B.Tech. Project report submitted to
Indian Institute of Technology,

In fulfillment of the requirements

for the degree of

Bachelor of Technology

in

Mechanical Engineering

by

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Under the supervision of

Prof. Sankha Deb

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INDIAN INSTITUTE OF TECHNOLOGY, KHARAGPUR

Certificate

This is to certify that the project report entitled ***“Inspection Robot”*** submitted by ***Sala Amrutha***(20MF10030) to the Indian Institute of Technology, Kharagpur towards the partial fulfillment of the requirements for the award of the degree of Bachelor of Technology in Mechanical Engineering of the Institute is a record of bona fide work carried out by him under my supervision and guidance during the Spring Semester of 2024.

……………………………………………………………….

Supervisor: Prof. Sankha Deb

Date:

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Date:

Declaration

I certify that

a) The work contained in this report is original and has been done by me under the guidance of my supervisor.

b) The work has not been submitted to any other Institute for any degree or diploma.

c) I have conformed to the norms and guidelines given in the Ethical Code of Conduct of the Institute.

d) I have adhered to the guidelines provided by the Institute in preparing the report.

e) Whenever I have used materials (data, theoretical analysis, figures, and text) from other sources, I have given due credit to them by citing them in the text of the thesis and giving their details in the references. Further, I have taken permission from the copyright owners of the sources, whenever necessary.

Acknowledgment

I want to express my sincere gratitude to my Bachelor thesis project supervisor Prof. Sankha Deb for his immense guidance and support throughout the thesis project. The precious insights provided by him proved to be extremely beneficial to me throughout my project.

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Abstract

The engineer is constantly confronted with the challenges of bringing ideas and design into reality. New machines and techniques are being developed continuously to manufacture various products at cheaper rates and higher quality. The pipe inspection robot with active pipe-diameter adaptability and automatic tractive force adjusting is developed for the long-distance inspection of main pipelines with different diameter series. Its physical design employs the scheme that three sets of circular wheeled leg mechanisms are circumferentially spaced out 120° apart symmetrically. This structural design makes it possible to realize the adaptation to pipe diameter and tractive force adjusting together. Based on analyzing the mechanical actions of the adaptation to pipe diameter and tractive force adjusting the related mechanical models are established, and their control system structure and control strategy are discussed. To verify the pipe-diameter adaptability and tractive force adjusting of the robot, related field experiments are implemented in the actual pipeline. The experimental results show that the theoretical analysis in this paper is valid and the prototype of this robot can work well in actual pipelines. Compared with other similar robots, this robot, which employs active mode for its adaptability to pipe diameter, can be adaptable to a wide range of pipeline diameters and automatically provide a stable and reliable tractive force with a strong capacity of tractive force adjusting. An ultrasonic sensor is mounted on the servomotor to detect obstacles in any direction.

Keywords: In pipe robot, Active pipe diameter adaptability; Obstacle Avoidance; pipeline inspection

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Introduction

Robotics is one of the fastest-growing engineering fields, presently they are used for a wide variety of work especially in manufacturing industries e.g., spot welding, loading and unloading of tools and workpieces, painting, etc.

Primarily, robots are designed in such a way that they reduce human intervention in labor-intensive and hazardous work environments; sometimes it is also used to discover inaccessible workplaces that are generally impossible to access by humans. The complex internal geometry and hazard content constraints of pipes require robots for inspection purposes. With these constraints, inspection of pipes becomes so necessary that tolerating it may lead to serious industrial accidents that contaminate the environment and loss of human lives too. For inspection of such pipes, robot requirements are needed especially to check the corrosion level of the pipe, recovery of usable parts from the pipe interior, sampling of sludge and scale formation on the pipe's internal surface, etc.

Why is this topic chosen?

Often, robots are used to do jobs that could be done by humans. However, there are many reasons why robots may be better than humans in performing certain tasks.

a) Speed: Robots may be used because they are FASTER than people at carrying out tasks. This is because a robot is a mechanism that is controlled by a computer - and we know that computers can do calculations and process data very quickly. Some robots MOVE more quickly than we can, so they can carry out a task, such as picking up and inserting items, more quickly than a human.

b) Accuracy: Accuracy is all about carrying out tasks with high precision. In a manufacturing factory, each item has to be made identically. When items are being assembled, a robot can position parts within fractions of a millimeter.

c) Hazardous (dangerous) Environments: Robots may be used because they can work in places where a human would be in danger. For example, robots can be designed to withstand greater amounts of heat, Radiation, and Chemical fumes than humans.

d) Repetitive Tasks: Sometimes robots are not much faster than humans, but they are good at simply doing the same job over and over again. This is easy for a robot, because once the robot has been programmed to do a job once; the same program can be run many times to carry out the job multiple times. And the robot will not get bored like a human.

e) Efficiency: Efficiency is all about carrying out tasks without waste. This could mean not wasting time and materials.

Problem Definition:

The inspection of pipes may be relevant for improving security and efficiency in industrial plants and for domestic purposes. These specific operations as inspection, maintenance, cleaning, etc. are expensive and hazardous, thus the application of the robots appears to be one of the most attractive

solutions. A lot of troubles caused by the piping network's aging, corrosion, cracks, and mechanical damage are possible. So, continuous activities for inspection, maintenance, and repair are strongly demanded. The robots with a flexible (adaptable) structure may boast adaptability to the environment, especially to the pipe diameter, with enhanced dexterity, maneuverability, and capability to operate under hostile conditions. Pipe inspection robots have been studied for a long time, and many original locomotion concepts have been proposed to solve the numerous technical difficulties associated with the change in pipe diameter, curves, and energy supply. Although an exhaustive review of the literature is impossible due to the limited space available, a few broad categories can be identified:

(I) For small sizes, many projects follow the earthworm principle consisting of a central part moving axially while the two end parts are provided with blocking devices connected temporarily to the pipe. Pneumatic versions of this concept have been proposed but they require an umbilical for power. For smaller diameters (10 mm or less), a piezoelectric actuation has been considered, according to the inchworm principle, or inertial locomotion driven by a saw-tooth wave voltage, or using vibrating fins with differential friction coefficients.

(II) For medium-size piping, classical electromechanical systems have been proposed with various architectures involving wheels and tracks, with more or less complicated kinematical structures, depending on the diameter adaptability and turning capability

(III) For large pipes, walking tube crawlers have also been proposed.

Literature Review

NAME OF THE PAPER	CONS	PROS	NAME OF THE AUTHOR
Design of pipe inspection Robot for All Pipeline Configurations	Complex Mechanism	The spring mechanism helps in better turning and adjusting the size of the robot according to the diameter	M B Kaushik, P Karthikeyan, A Jothilingam Madras Institute of Technology, Anna University, Chennai, India
A Multi-link In-pipe Inspection Robot Composed of Active and Passive Compliant Joints	Experiments in longer pipeline environments can't be conducted.	The inspection robot has two passive-compliant joints and a single active compliant middle joint to pass through the bend, T-branch, and vertical pipes.	Atsushi Kakogawa and Shugen Ma
Adapting Mechanisms for In-Pipe Inspection Robots	The paper does not provide any experimental results or potential impact of the inspection robots.	The paper provides valuable insights into the design and adapting mechanisms of wall-pressed inspection robots	Calin Rusu and Mihai Olimpiu Tatar
Design and Development of In-pipe Inspection Robot for various pipe sizes	Here the model doesn't have any sensors on the robot for locomotion	It is better in steerability and diameter adaptability than existing screw-driven wall presses wheel type pipe inspection robots.	Atul Gargade1 and Shantipal Ohol Mechanical Engineering Department, College of Engineering Pune, India

Performance indicator	Wheel type robot			Caterpillar type robot		Without Wheel Type Robot		
	Wheel type robot (Simple structure)	Wheel type (wall pressed type)	Screw drive type robot	Caterpillar Robot (simple structure type)	Caterpillar Robot (wall pressed type)	Leg type robot	Inchworm type robot	Snake type robot
Vertical Mobility	Poor	Very Good	Very Good	Fair	Very Good	Very Good	Fair	Fair
Steerablity	Very Good	Fair	Fair	Fair	Fair	Very Good	Fair	Fair
Size and shape adaptability	Poor	Very Good	Fair	Poor	Very Good	Very Good	Fair	Very Good
Flexibility of body	Rigid	Rigid	Less flexible	Rigid	Rigid	Rigid	Flexible	Flexible
Stability of robot	Poor	Very Good	Very Good	Fair	Fair	Fair	Fair	Fair
Moztion efficiency	Fair	Fair	Very Good	Fair	Very Good	Very Good	Very Good	Fair
Number of actuators	Fair	Fair	Less	Less	Less	More	More	More
Wireless control	Fair	Very Good	Fair	Fair	Fair	Poor	Poor	Poor

Fig 1: Comparison of different types of Robots

Ref: Nayak, A., & Pradhan, S. K. (2014). Design of a new in-pipe inspection robot. *Procedia Engineering*, *97*, 2081-2091

Research Gap:

The research papers discussed have intricate designs and mechanisms, making them challenging to understand fully. They lack detailed explanations of how these mechanisms work and operate. Moreover, the experiments conducted in these papers are limited in scope and cannot replicate conditions found in longer pipelines or every type of pipeline. One major drawback is the absence of ultrasonic sensors mounted on the robot body. These sensors are crucial for detecting obstructions and pinpointing their locations inside the pipe. Without them, the robot's ability to navigate and perform its tasks effectively may be compromised. Additionally, some papers fail to provide the necessary experimental and mathematical analysis of the robot model. These analysis are essential for validating the robot's performance and understanding its capabilities accurately. Without such analysis, it's difficult to assess the reliability and effectiveness of the proposed robotic systems.

Existing models

In-pipe Inspection Robots (IPIRs) are widely used in petrochemical, water supply, and fluid transportation industries. Many researchers have done work to develop new in-pipe robots to enhance various aspects of in-pipe inspection robots like vision, control, and motion or robot. The research work of these researchers is reviewed to find the design philosophy, capabilities, and limitations of different types of robots based on the review it has been found that the in-pipe robot can be classified into three main categories and eight subcategories as depicted below.

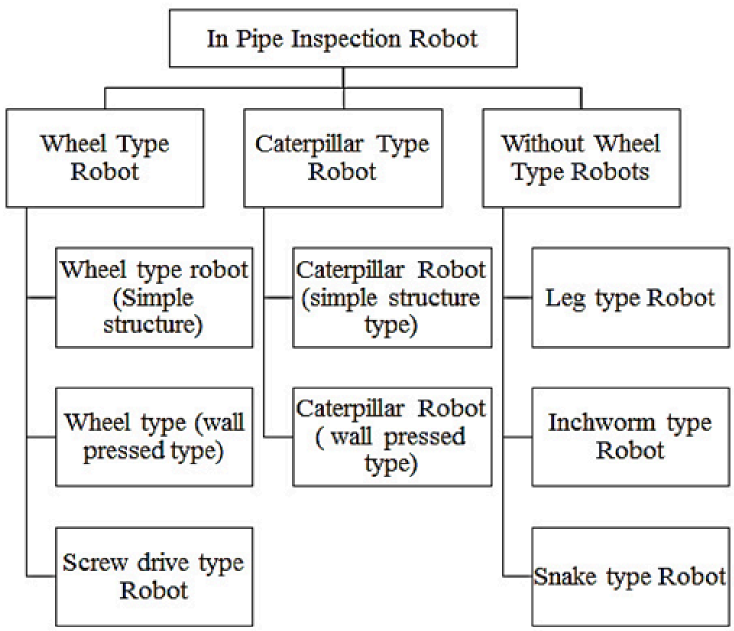

Fig 2: Flowchart of different types of inspection robots

Ref: Nayak, A., & Pradhan, S. K. (2014). Design of a new in-pipe inspection robot. *Procedia Engineering*, *97*, 2081-2091

In wheel-type robots, wheels are directly connected to motors to get the desired locomotion. They have a simple structure, and better velocity control with a small car-like structure while in wall wall-pressed robot, the wheels are mounted on the elastic arms which provide adaptability and required frictional force to the robot. Screw-type robots have two modules a stator and a rotor. The rotor is composed of three tilted wheels at a specific angle. The rotor is directly connected to the motor and it converts the rotation of the motor into translation of the robot. The stator of a screw drive type robot consists of three straight wheels which provide stability to the robot and prevent the robot from reacting force, comes due to the rotation of the rotor. Caterpillar type robot has two categories viz. caterpillar type robot simple structure and caterpillar robot wall pressed type structure. Caterpillar robot's simple structure has belt-bound wheels that are connected to actuators. Belt-bound wheels provide more friction to the robot and make it able to move on uneven surfaces. Wall-pressed robots are designed to climb vertical and inclined pipelines of rough interiors. Without wheel type, robots can be classified into three categories i.e. inchworm type robots which have inch worm type motion in the pipeline with the help of two clamping and one elastic module. Snake-type robots have many articulated active modules and Leg type robots can climb vertical and horizontal pipelines having ‘L’, ‘T’, and ‘Y’ joints.

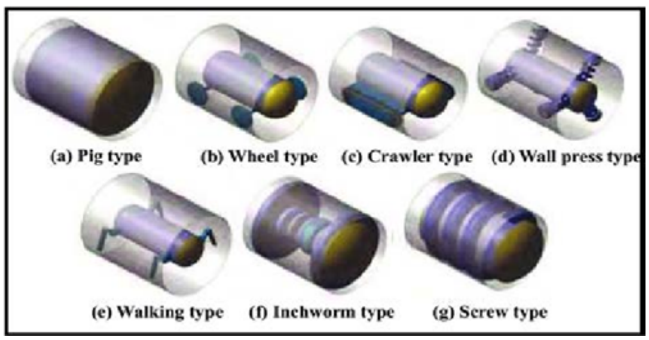

Fig3: Prototypes of different types of robots

Ref: Baballe, M. A. (2022). Robotic Inspection Monitoring System for Pipelines. *Journal of Artificial Intelligence and Systems*, *4*(1), 50-64.

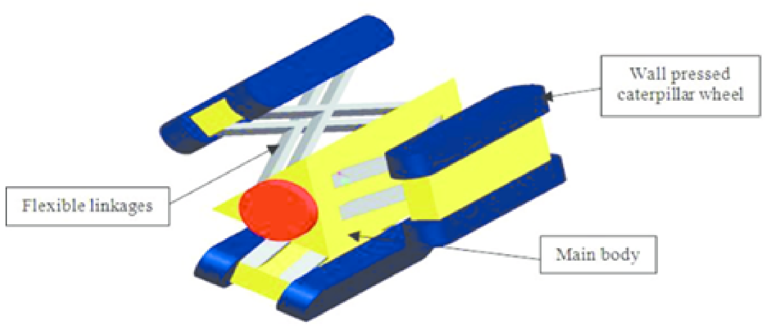

Fig4: Caterpillar Type Inspection Robot

Ref: Roslin, N. S., Anuar, A., Jalal, M. F. A., & Sahari, K. S. M. (2012). A review: Hybrid locomotion of in-pipe inspection robot. *Procedia Engineering*, *41*, 1456-1462.

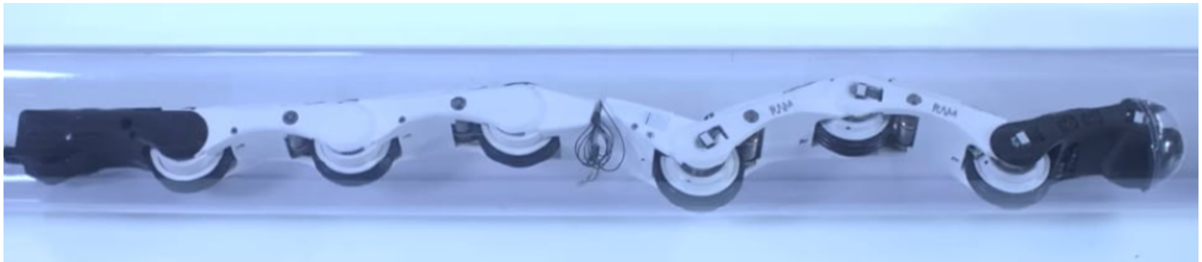

Fig5: Snake type robot
Ref: https://www.youtube.com/watch?v=vkndACl5YjA

Fig6: Flexible Robot
Ref: https://techxplore.com/news/2023-09-flexible-robot-small-spaces.html

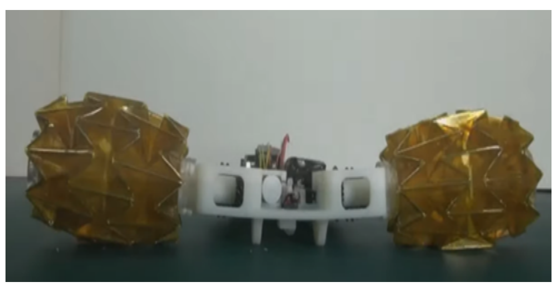

Fig7: Origami wheeled robot
Ref: https://www.youtube.com/watch?v=EiInnP8RzFI

Objectives

- Making a circular robot with three wheels that fits within a pipe.
- Transforming the robot in a way that it can adjust according to the diameter of the pipe.
- Sensing the object in the way and avoiding the obstacle using sensors.
- Installing an ultrasonic sensor that can rotate and detect the pathway present in all directions.
- Making the robot move forward and backward and controlling the speed of the robot using a potentiometer.

Scope Of The Project

The main scope of our FINAL YEAR MECHANICAL project is to locate defects due to corrosion and obstacle at the inner side of the pipe line. Nevertheless, damage still occurs, which reduces the strength of the pipe. If it goes undetected and becomes severe, the pipe can leak and, in rare cases, fail catastrophically. So, extensive efforts are made to mitigate defects. So, we proposed a new design in inspecting pipelines.

The 3D model of the designed inspection robot consists of a middle part in which the arduino uno, motor driver and battery are kept. There are three cylinders which were attached to the middle part inside which there will be a spring which can help in decreasing the size of the robot according to the pipe diameter. Each wheel is connected to a DC motor which in turn helps the wheel to move. The speed of the wheels can be controlled by the potentiometer.

Methodology

Power given to the robot

⬇️

Robot sets in motion..

⬇️

Robot encounters an obstacle

⬇️

Servo Motor is turned on!

⬇️

Ultrasonic sensor rotates and directs the robot to the other side

⬇️

Stops and takes a step back when it reaches the end!

⬇️

Wheels turn to return

⬇️

Robot stops!

Main Components and it's working in the Project:

1) DC Motor: The project is powered by using three permanent magnets direct current motor. The gearbox is attached to the DC motor. On the shaft of the DC motor, a nut is provided for mounting it on the link. The wheel is directly connected using a nut & and bolt on the shaft of the motor.

2) Wheels: Here, we will have 3 wheels. The circumference of the wheel is provided with a rubber grip so that it will not slip inside the pipe. Three wheels are powered by using a DC gear motor. These wheels are used to grip, pull, and push the robot inside the pipe.

3) Spring Arrangement: Springs are flexible machine elements, used for the controlled application of force (or torque) or for storing and release of mechanical energy. Flexibility (elastic deformation) is enabled due to cleverly designed geometry or by the use of flexible material. In our model, we are using a spring to adapt the robot according to the diameter of the pipe. Parts that help in changing the diameter of the robot: cylinder, piston and its base, cap, spring, motor, and wheels are connected to the piston as shown.

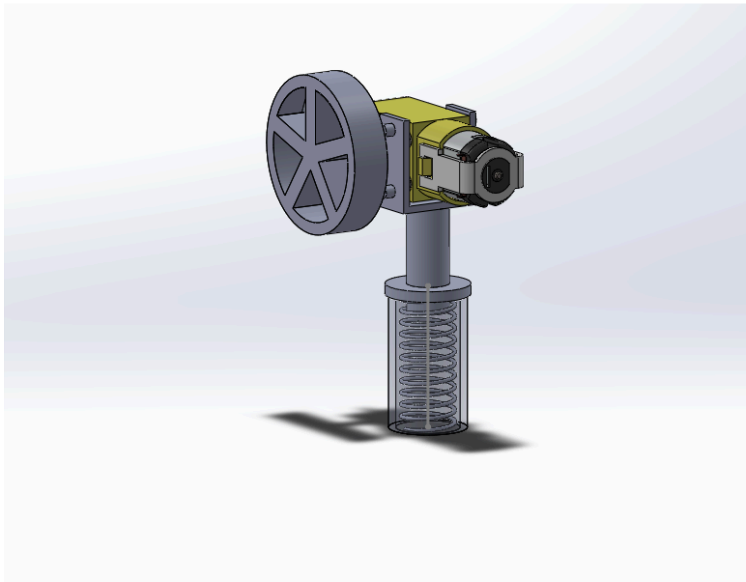

Fig8: Assembly of parts responsible for the compression.

When the diameter of the pipe decreases, a normal force is exerted on the piston which in turn compresses the springs(present inside the cylinders) on all the 3 sides up to a certain extent. It reverts when the diameter increases again.

4) Wireless Camera: Wireless cameras are wireless transmitters carrying a camera signal. The camera is wired to a wireless transmitter and the signal travels between the camera and the receiver. This works much like a radio. Wireless cameras also have a channel. The receiver has channels to tune in and then the picture is obtained. The wireless camera picture is sent by the transmitter the receiver collects this signal and outputs it to a computer or TV Monitor depending on the receiver type. This is used for getting live footage of the internal circumference of the pipe. This is attached on top of a servo so that the whole circumference gets inspected and not just the static view through the front part.

5) Fasteners (Nut and Bolt): The nut bolt used for making a pipe inspection robot is M6 size. The M6 size is selected because they are light in weight and can easily take the load of our mechanism. Majorly they are used in our project for pivoting the mechanism and for tightening the Bush on the shaft.

6) Battery: The battery is an electrochemical converting chemical energy into electrical energy. The main purpose of the battery is to provide a supply of current for operating the cranking motor and other electrical units. Its specifications are 12v and 3 amps.

7) Obstacle Avoidance (Sensors): An Ultrasonic sensor, which is powered by Arduino UNO, is used to sense the obstacles in the path by calculating the distance between the robot and the obstacle. If the robot finds any obstacle it changes direction and continues moving. The basic principle behind the working of an ultrasonic sensor is to note down the time taken by the sensor to transmit ultrasonic beams and receive the ultrasonic beams after hitting the surface. Then further the distance is calculated using the formula. In this project, the widely available HC-SR04 Ultrasonic Sensor is used. In our model, an ultrasonic sensor is attached on top of a servo motor so that it will be able to detect in any direction we want(even when the robot is moving backward).

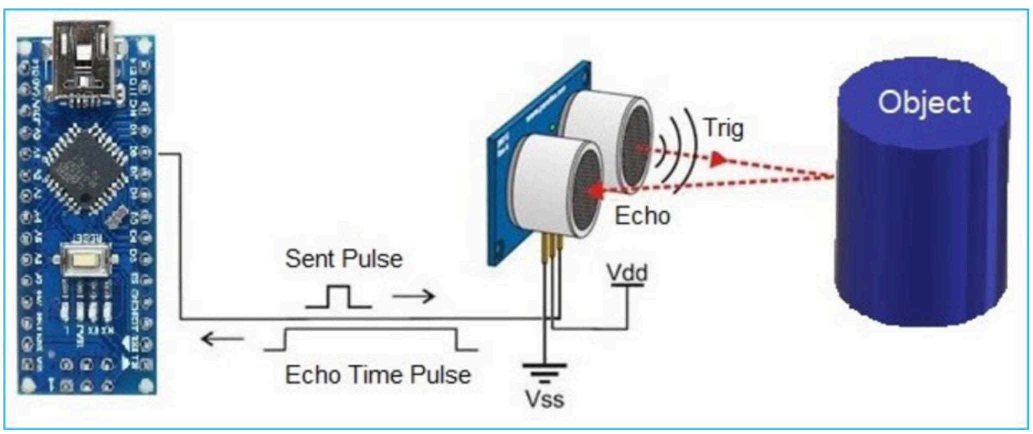

Fig9:

Working of UV Sensor

Ref: https://www.instructables.com/Obstacle-Avoiding-Robot-/

All the components are powered by Arduino, an L298n motor driver module, and 3 LiPo batteries.

The Manufactured model is printed with the help of a 3d printer using polylactic acid (PLA).

Hence we made use of the existing facilities of the above-mentioned elements in a synchronised manner to achieve our purpose!

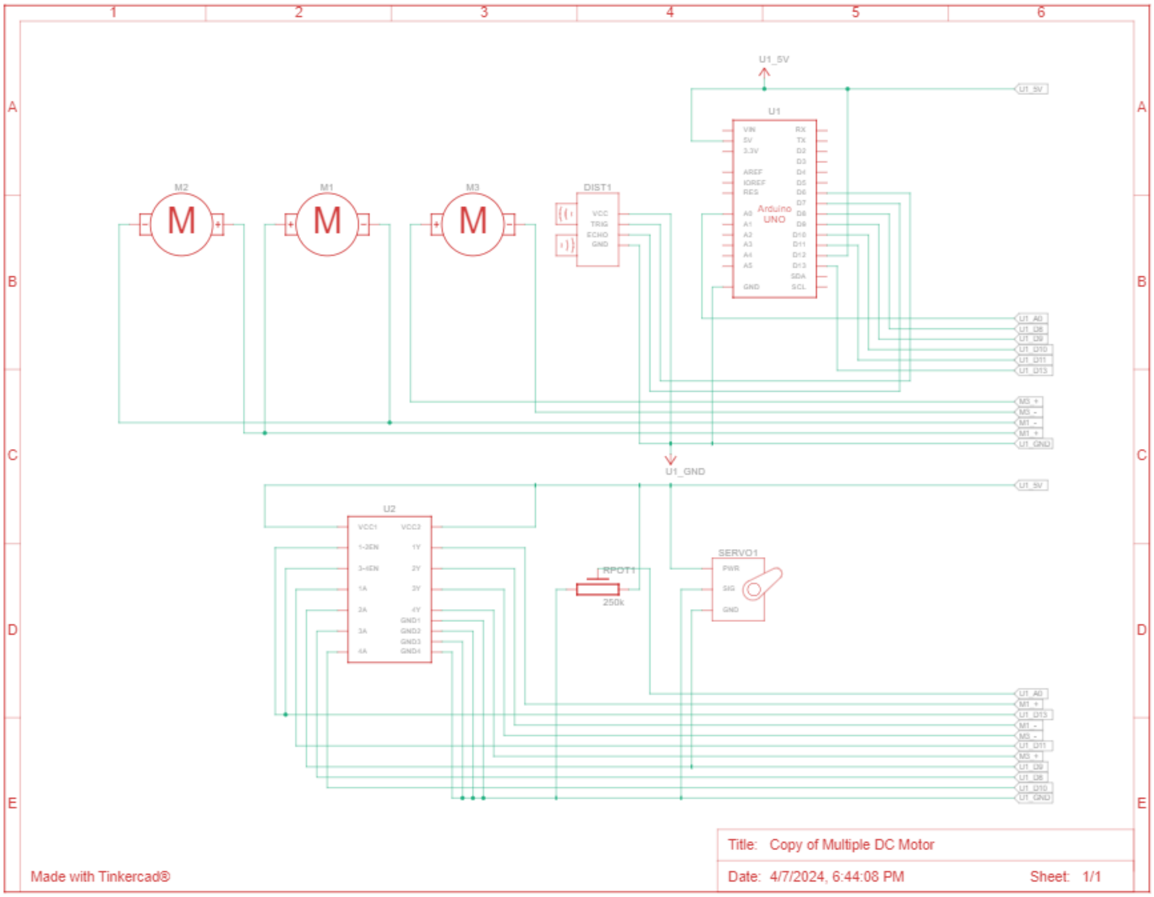

Fig10: Schematic view of the circuit

Analysis and Result

From the designed model of the pipeline inspection robot, the diameter of the robot can be increased and decreased. Depending on the diameter of the pipe, the diameter of the robot will change with the help of the spring attached to it. The spring can also help the robot by making it easier to take turns in the pipelines. The robot is installed with sensors and also a camera which helps in the live recording of the condition of the pipelines.

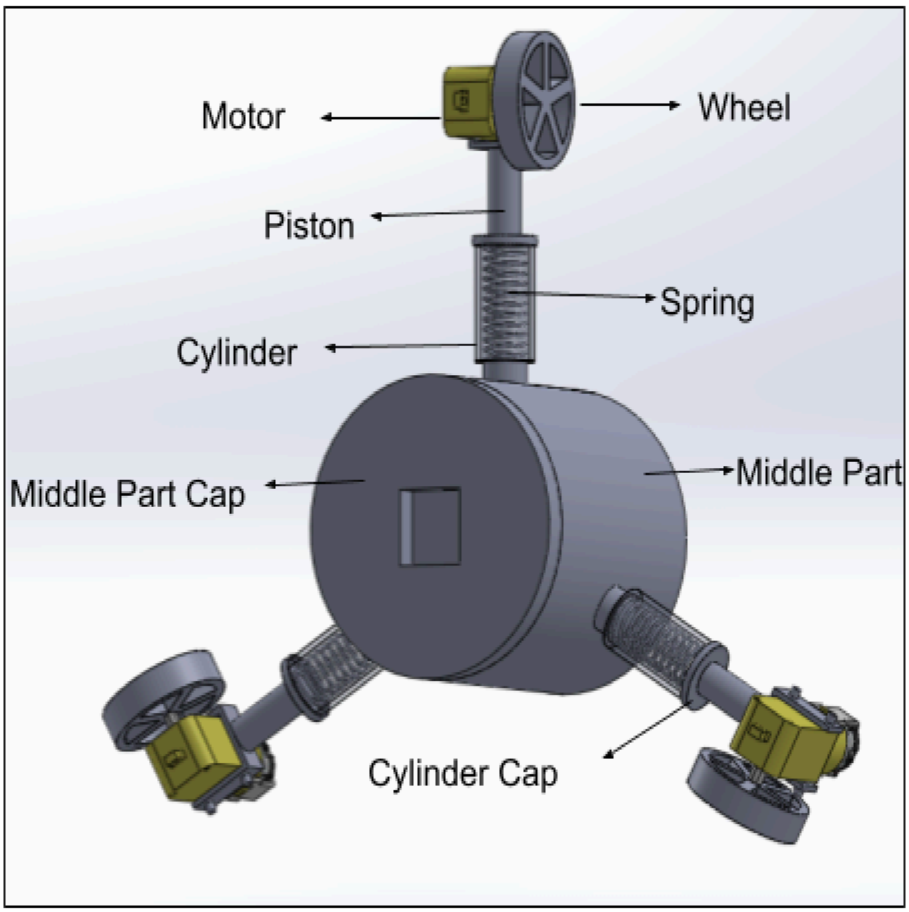

Fig11: Final assembly

Specifications of Robot

Specification	Value
Diameter of the middle part	100mm
Length and diameter of the cylinder	40mm and 18mm
Length and diameter of the piston	56mm and 12mm
Diameter of the wheel	45mm
Spring length and diameter	30mm and 16mm
Piston base diameter	16mm

Some of the analysis of the model from ansys:

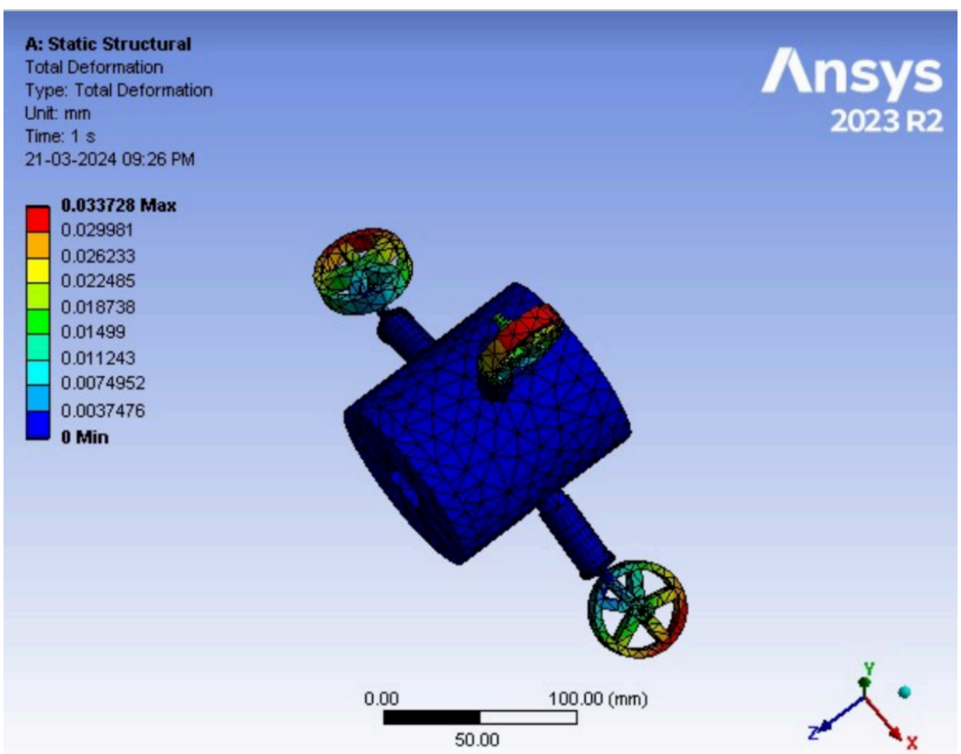

Fig12: Total deformation

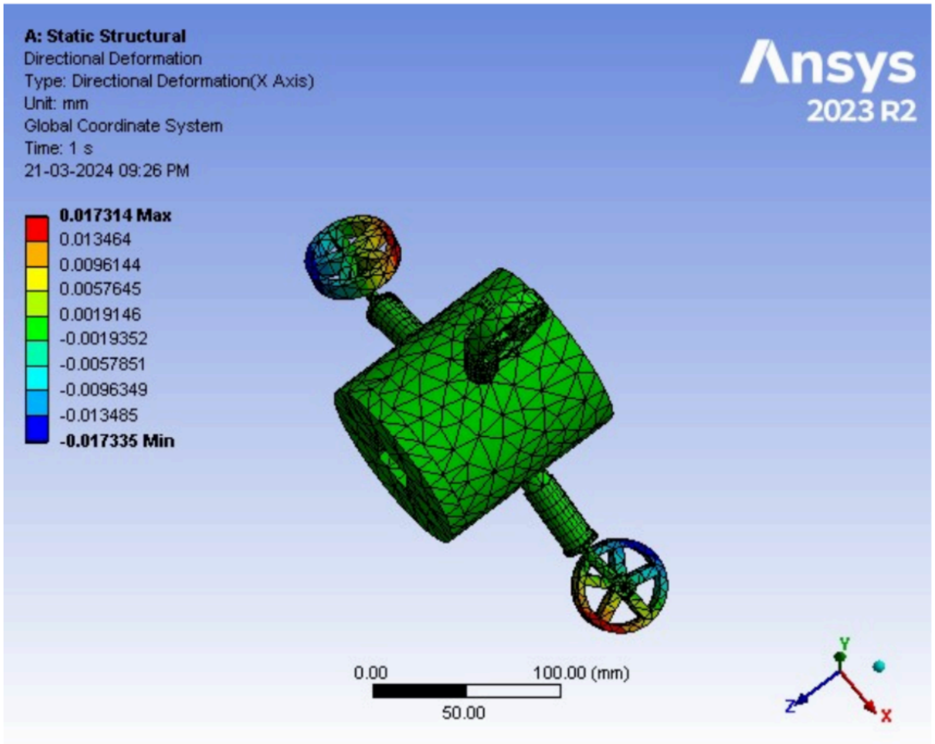

Fig13: Directional deformation

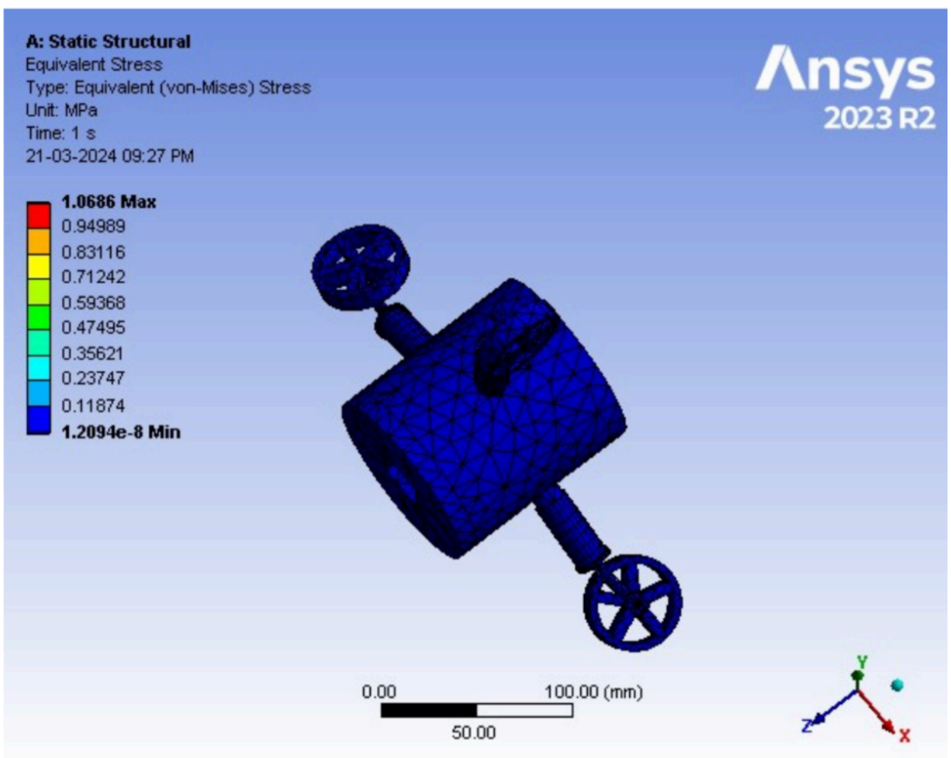

Fig14: Equivalent stress

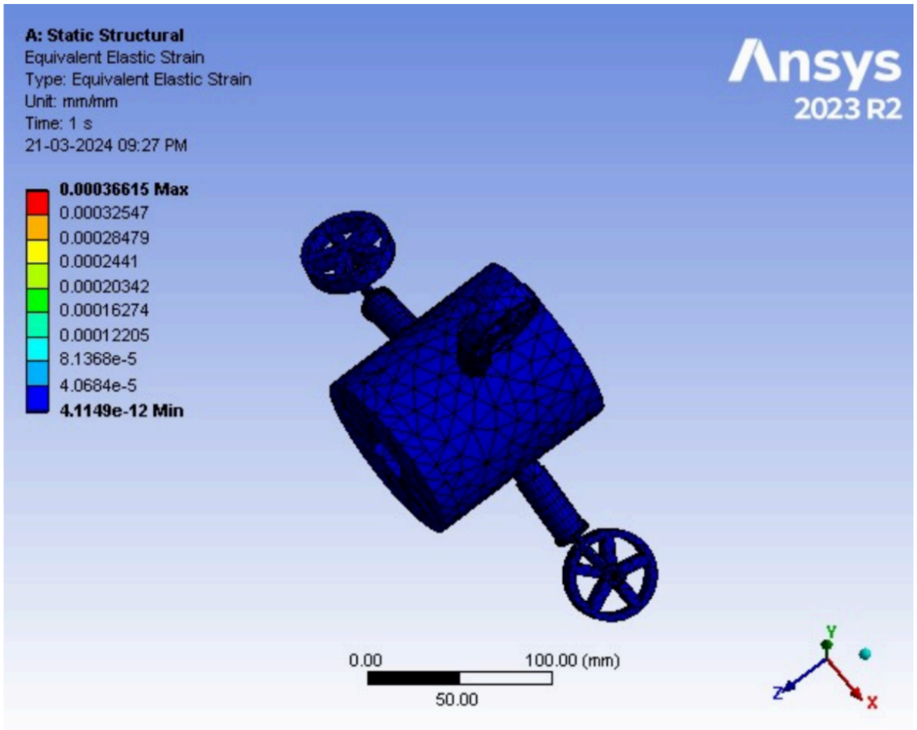

Fig15: Equivalent Elastic Strain

Conclusion

In conclusion, the design of the pipe inspection robot is successfully demonstrated. The camera can be installed for inspection purposes, which gives a clear view of cracks, obstacles, damages, rust, and holes. Three springs are mounted on the robot which works very well. This robot can travel in pipes of varying sizes. Because of the spring, the robot gets a very good grip which does not let it slip. The robot is operated by using a battery which is installed inside and a potentiometer to control the speed of the robot. On comparing the available pipe inspection robots namely PIG type, caterpillar type, Inch Worm, Lead screw, and walker type it was found that vertical climbing of the robot and multi elbow turning configuration of the robot was difficult. In the developed model a suitable spring-type flexible arrangement is provided for effective vertical climbing and complex elbow-turning configuration.

Future Scope

- A camera can be installed in the prototype to satisfy the above objectives and for better efficiency.
- We can also make the robot in such a way that it can rectify the damage in the pipeline.
- It can be waterproof so that it can go into the pipeline even where is water and function without any problem.
- AI technologies can be used to analyze and detect the pipeline's health status by processing large amounts of data changes in pipeline conditions.
- The robot can be created with GPS and voice control capabilities.

In summary, the pipeline inspection robot has unlimited prospects for development. It can help reduce labor and resource costs while also increasing inspection efficiency and accuracy. Therefore, it has become a necessary technology for the pipeline inspection industry and will undoubtedly provide endless possibilities for applications.

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Appendix-1

Code and circuit of the robot:

/*------ Arduino Inspection Robot Code----- */

```
#include  <NewPing.h>
#include  <Servo.h>

int in3  = 4;
int in4 = 5;
int ConA = 6;
int speed1;
#define trig_pin  A1 //analog input 1
#define echo_pin A2 //analog input 2
#define maximum_distance  200
boolean goesForward = false;
int distance = 100;

NewPing sonar(trig_pin,  echo_pin, maximum_distance); //sensor function
Servo servo_motor; //our servo  name


void setup()
{
  pinMode(in3, OUTPUT);
  pinMode(in4, OUTPUT);
  pinMode(ConA, OUTPUT);

  servo_motor.attach(10); //our servo pin

  servo_motor.write(180);
  delay(2000);
  distance = readPing();
  delay(100);
  distance = readPing();
  delay(100);
  distance = readPing();
  delay(100);
  distance = readPing();
```

```
  delay(100);
}

void loop(){

  int distanceRight = 0;
  int distanceLeft = 0;
  int distanceBack = 0;
  delay(50);

  if (distance <= 45)
  {
    moveStop();
    delay(300);
    TurnMotorBackward();
    delay(400);
    moveStop();
    delay(300);
    distanceRight = lookRight();
    delay(300);
    distanceLeft  = lookLeft();
    delay(300);
    distanceBack = lookBack();
    delay(300);
    TurnMotorBackward();
  }
  else
  {
    TurnMotorForward();
  }
    distance = readPing();
}

int  lookRight(){
  servo_motor.write(90);
  delay(500);
  int distance =  readPing();
  delay(100);
  servo_motor.write(115);
  return distance;
```

```
}

int  lookLeft(){
  servo_motor.write(270);
  delay(500);
  int distance = readPing();
  delay(100);
  servo_motor.write(115);
  return distance;
  delay(100);
}

int  lookBack(){
  servo_motor.write(0);
  delay(500);
  int distance = readPing();
  delay(100);
  servo_motor.write(115);
  return distance;
  delay(100);
}

int  readPing(){
  delay(70);
  int cm = sonar.ping_cm();
  if (cm==0){
    cm=250;
  }
  return cm;
}

void moveStop()
{
  digitalWrite(in3,  LOW);
  digitalWrite(in4,  LOW);
}

void TurnMotorForward()
{ //We create a function which control the direction and speed
  if(!goesForward)
```

```
  {
   goesForward=true;
   digitalWrite(in3, LOW); //Switch between this HIGH and LOW to change direction
   digitalWrite(in4, HIGH);
   speed1 = analogRead(A0);
   speed1 = speed1*0.2492668622; //We read the analog value from the potentiometer calibrate it
   analogWrite(ConA,speed1);// Then inject it to our motor
  }
}

void TurnMotorBackward()
{ //We create a function which control the direction and speed
  goesForward=false;
  digitalWrite(in3, HIGH); //Switch between this HIGH and LOW to change direction
  digitalWrite(in4, LOW);
  speed1 = analogRead(A0);
  speed1 = speed1*0.2492668622; //We read the analog value from the potentiometer calibrate it
  analogWrite(ConA,speed1);// Then inject it to our motor
}
```

Tinker Cad Circuit:

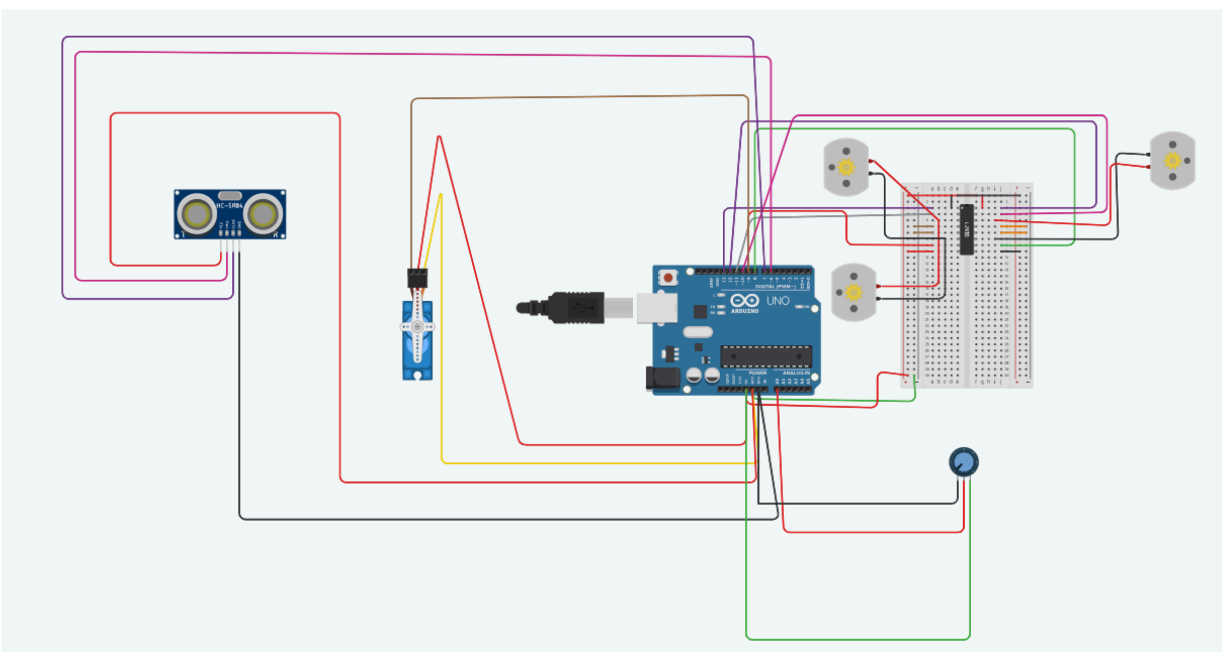

Fig16:Connections using tinkercad

Manufactured model along with the connections:

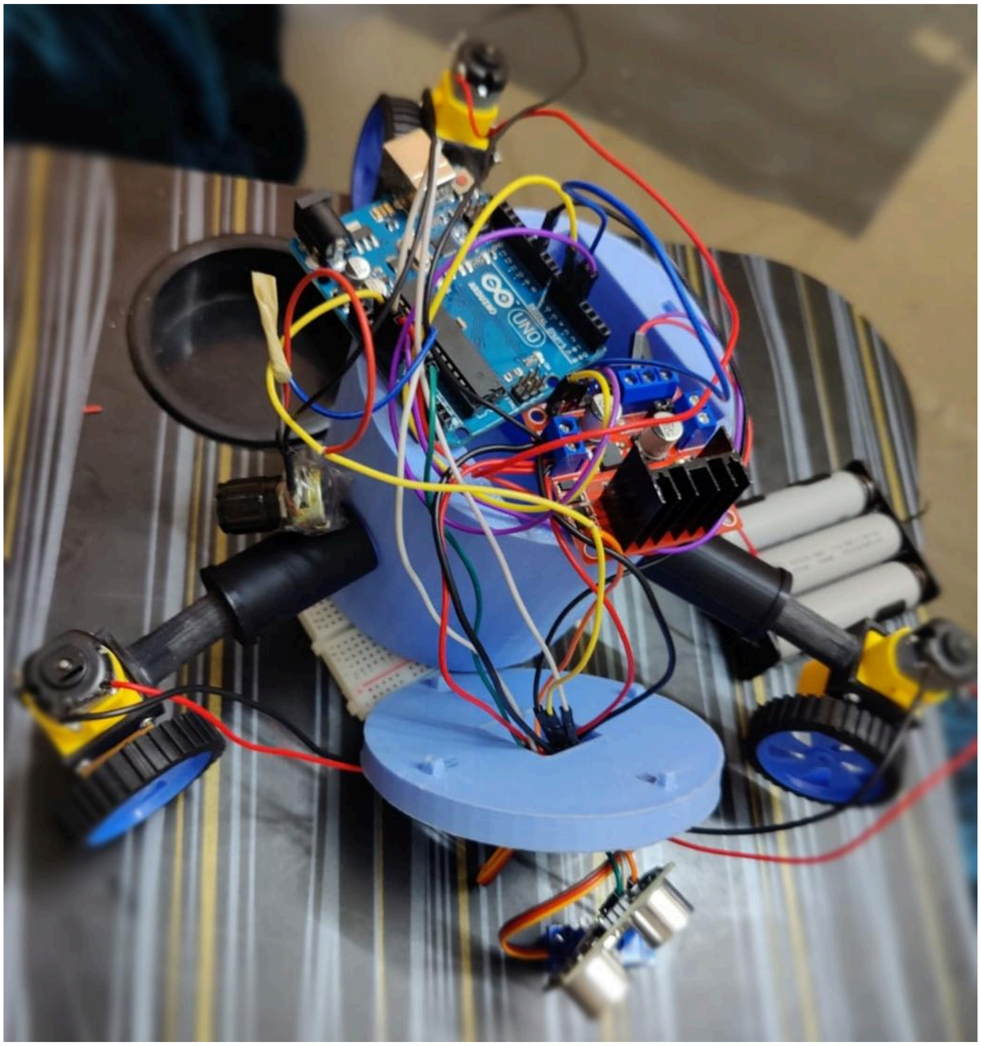

Fig17:3D model with circuit

Drive link for working prototype video:

https://drive.google.com/drive/folders/1N-S1K7vl12mJ3bRK8heVJzPxIKRSBoVD?usp=sharing

Appendix-2

Pictures of the model and circuit diagram:

CAD model:

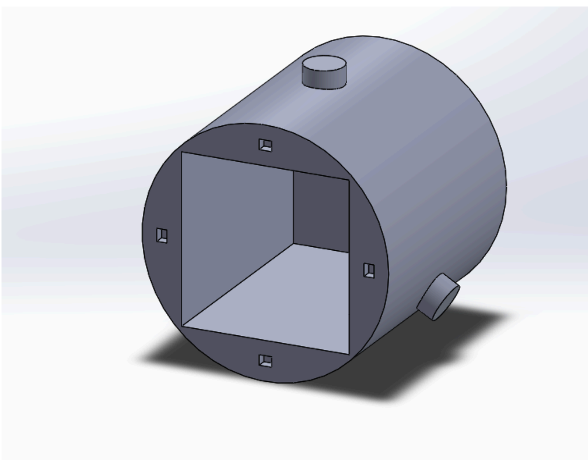

Fig18: Middle part

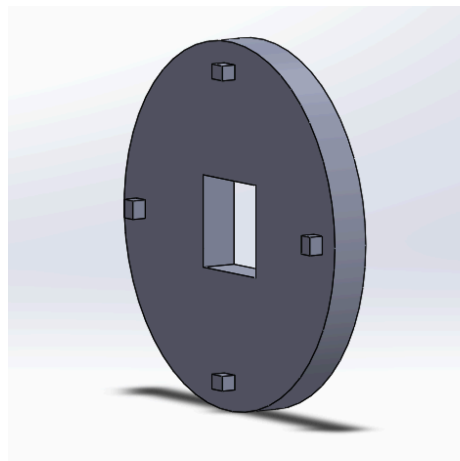

Fig19: Middle part cap

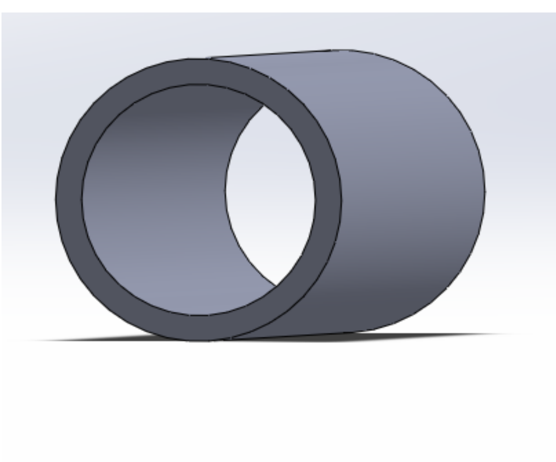

Fig20: Cylinder

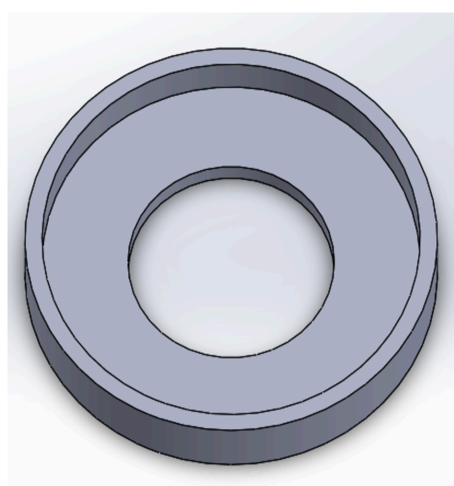

Fig21: Cylinder cap

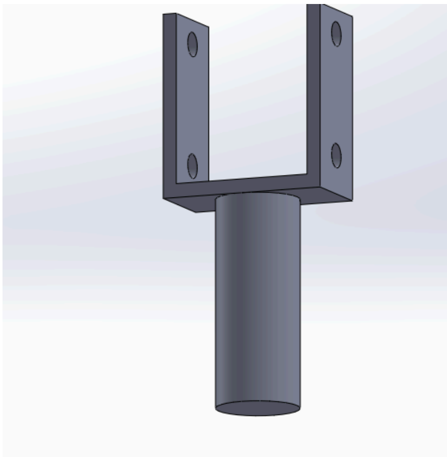

Fig22:Piston

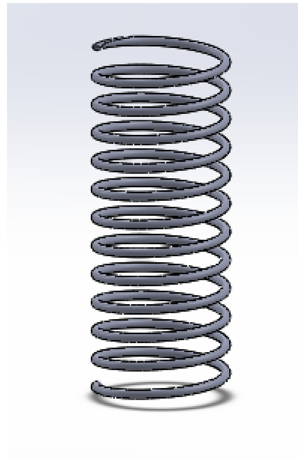

Fig23: Spring

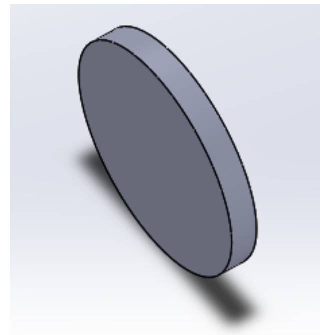

Fig24: Piston base

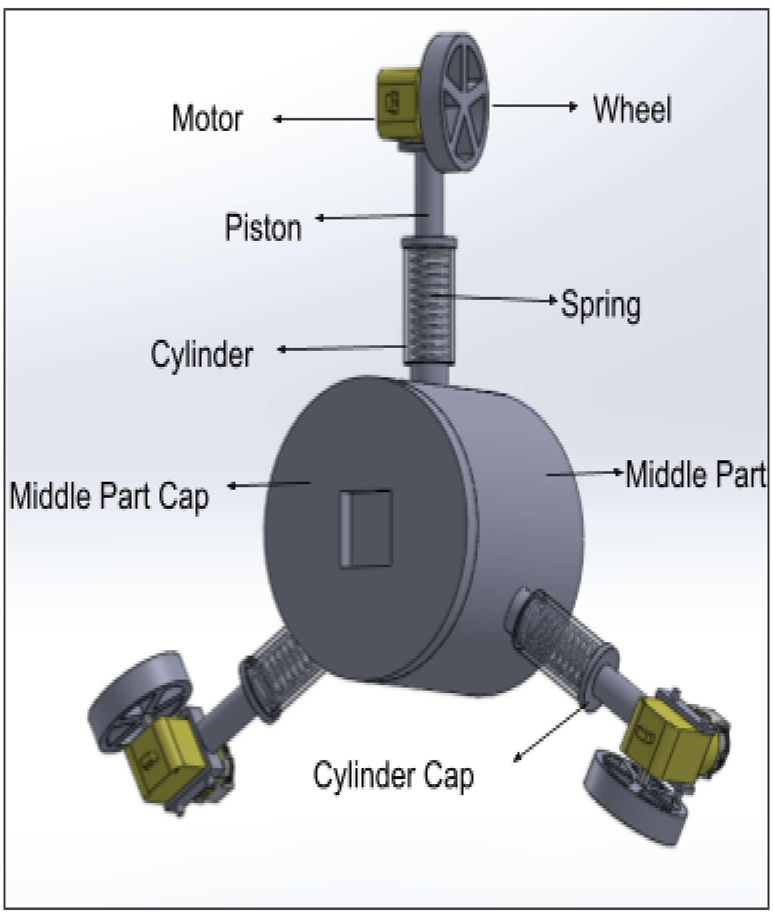

Fig25: Complete Assembly