PIPE TRAVERSING ROBOT

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ABSTRACT

As technology advances, the demand for automated systems has increased exponentially. The development of robotic systems has made it possible to explore and operate in remote and hazardous environments. One such application is the inspection of underground pipelines, which requires a mobile robot that can traverse inside the pipeline, inspecting and repairing any damage that may occur. For the rover, the diameter of the pipe is required minimum diameter of the pipe is 274mm and the maximum diameter of the pipe is 324 mm.

The rover is equipped with advanced sensor cameras, and communication systems that allow it to transmit real-time data to operators. The system operates on a track-driven mechanism that provides stability and agility to traverse through the pipeline. The rover's design also includes a modular and lightweight structure that allows for easy deployment and transportation. The system can operate autonomously or can be controlled remotely by operators, providing greater flexibility in the inspection process.

I. INTRODUCTION

A pipe-traversing rover is a specialized robot designed to navigate and explore the inside of pipes, ducts, and other enclosed spaces. Robots come with a diverse set of sensors and tools that enable them to accomplish a wide array of tasks, such as conducting inspections, performing maintenance operations, collecting data, and monitoring the environment. One of the key challenges of designing a pipe-traversing rover is ensuring that it is small and flexible enough to navigate through narrow pipes, but also robust enough to withstand the harsh environments it may encounter. Many pipe-traversing rovers are built using lightweight materials and feature a modular design, which allows them to be customized for different types of applications and environments. Another important aspect of pipe-traversing rovers is their mobility systems. These robots may use wheels, tracks, or other mechanisms to move through pipes, depending on the specific application. Additionally, these robots can come equipped with sensors and cameras that enable them to create a map of their environment and move around independently.

In addition to their mobility systems, pipe traversing rovers may also be equipped with a range of tools and instruments, such as cameras, sensors, lasers, and grippers. These tools allow the robot to perform tasks such as inspecting pipes for damage or leaks, cleaning pipes, and collecting data on environmental conditions. One of the key advantages of using a pipe-travesing rover is that it allows for non-invasive inspection and maintenance of pipes and other enclosed spaces. This can be particularly important in industries such as oil and gas, where pipelines can be hundreds or even thousands of miles long and are often inspecting and cleaning the pipes in buildings, or for exploring underground tunnels and other enclosed spaces. Despite their potential benefits, designing and building a pipe-traversing rover can be a complex and challenging process. Engineers and robotics experts must consider a range of factors, from the robot's size and shape to its power requirements and communication systems. However, as technology continues to advance, pipe-traversing rovers are becoming increasingly sophisticated and capable. With their ability to explore and inspect the inside of pipes and other enclosed spaces, these robots are poised to play an increasingly important role in a wide range of industries and applications.

The data collected by the pipe traversing rover is transmitted to a control room where it is analyzed and use to create a detailed report on the condition of the pipeline. This report can be used to identify areas that need maintenance, and to develop a plan for repairs or replacement. The pipe traversing rover is a cost-effective solution for pipeline inspection. It is capable of functioning for an extended duration without requiring any maintenance. recharged, and its small size means that it can be easily transported to different locations. This makes it ideal for use in remote areas or offshore installations.

Overall, the pipe traversing rover is an innovative technology that has transformed the way pipelines are inspected and maintained. It provides a safer, more efficient, and cost-effective solution for ensuring the integrity of pipelines, and it is set to become an essential tool in the oil and gas industry.

located in remote or inaccessible areas. In addition to their industrial applications, pipe traversing rovers may also have a range of other uses. For example, they could be used for

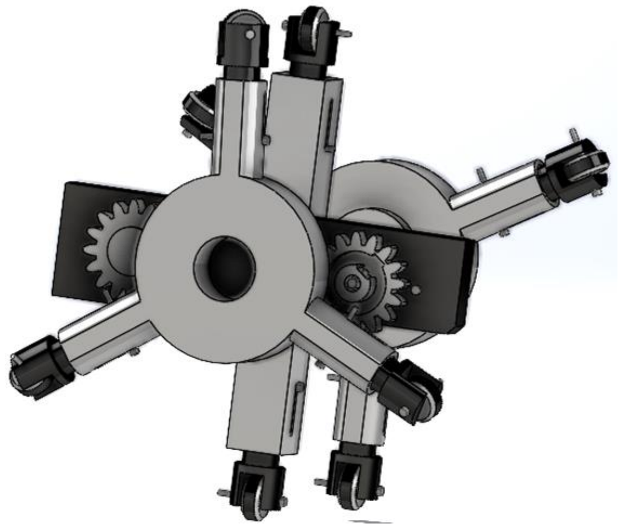


Fig.1. Pipe Traversing Rover (Solidworks Design)

II. CONFIGURATION OF ROVER

A. Components and Construction of the Rover

Firstly, it is important to ensure that the correct template for the paper size is being used. This template has been designed specifically for the US-letter paper size and should not be used for A4 paper as the margin requirements may be different. It is recommended to use the appropriate template for the paper size being used to ensure the document meets the desired formatting requirements. The inspection robot for pipes was designed based on the maximum and minimum diameter of the intended pipe diameter traversal. The circular diameter was designed to fit the minimum pipe diameter, while the length of the robot was determined concerning the critical points of the short elbow pipe of the minimum pipe. In addition, the robot is equipped with motors for the movement of the wheels. This design ensures the robot can traverse pipes of various diameters while maintaining stability and maneuverability. The actual image of the pipe inspection robot is shown in Fig. I.

It is important to note that this design may not be suitable for all pipe inspection applications, and further customization may be required depending on specific needs and requirements. The pipe traversing rover is a unique piece of machinery that is designed to be compact and mobile in tight spaces. When compressed with the help of spring, the rover can travel in a small size of pipe the diameter of the pipe is 274mm, allowing it to fit through narrow gaps and passages. This makes it ideal for use in pipeline inspection and maintenance, as it can easily navigate through small openings in the pipeline

However, when the rover needs to cover a larger area, it can expand with the help of spring then the rover can travel in a small size of pipe the diameter of the pipe is 322mm. This increased size allows it to traverse more challenging terrain and cover a greater distance, making it a versatile tool for a range of applications. The ability to switch between compressed and expanded modes is a key feature of this rover, allowing it to adapt to the needs of different tasks and environments. Despite its small size, the pipe traversing rover is equipped with advanced technology, including cameras and sensors, that allow it to gather data and images as it moves through the pipeline. This information can then be used to identify any issues or areas that require maintenance, helping to ensure the safe and efficient operation of the pipeline. Overall, the pipe traversing rover is a valuable asset for any company that operates pipelines, providing a cost-effective and efficient solution for inspection and maintenance tasks. The construction of a pipe-traversing rover can vary depending on the specific application and requirements. However, most rovers are designed to be modular, with components that can be easily replaced or upgraded as needed. The construction of the rover should also take into account the environment it will be operating in, including the size and shape of the pipe, the presence of any obstacles or hazards, and any potential sources of damage or wear.

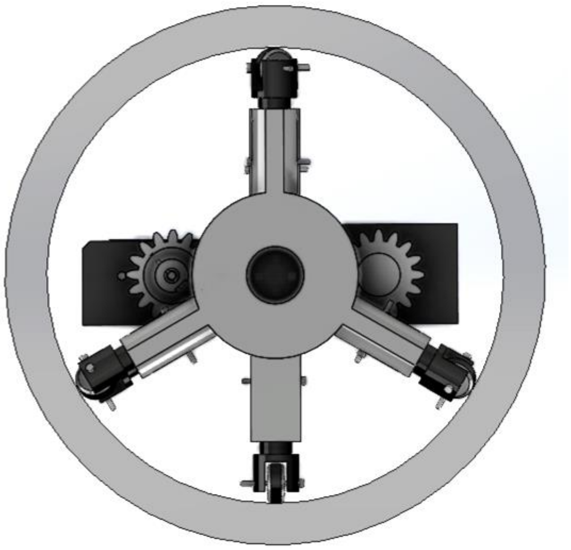


Fig.2. In **-** Pipe compression of the Rover

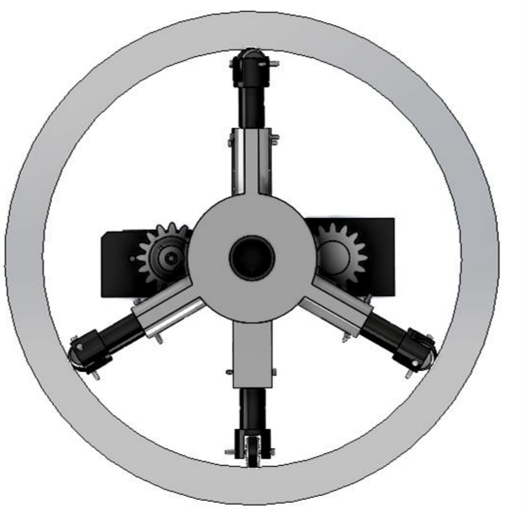


Fig.3. In **-** Pipe expansion of the Rover

B. ***Kinematics of screw drive type rover***

The kinematics of a screw drive type robot in a pipeline is dependent on several factors. Firstly, it is assumed that all wheels of the robot are in contact with the inner surface of the pipeline. This is important as it allows the robot to move along the pipeline without slipping or losing traction. Additionally, the mobility of the robot is generated by a combination of the motor, tilted wheels and supporting springs on each unit. These components work together to control the movement and direction of the robot within the pipeline. The helical motion of the screw drive type robot is also dependent on the inner shape of the pipeline. This is because the robot's screw drive mechanism is designed to fit and move along the contours of the pipeline. The pitch of the robot's movement is determined by the wheel tilt angle of the rotor, which controls the rate at which the robot moves forward. Overall, these assumptions and factors play a crucial role in driving the kinematics of a screw drive type robot in a pipeline, enabling it to move efficiently and effectively through the pipeline with only one degree of freedom. The wheels are designed to maintain constant contact with the inner surface of the pipe, ensuring efficient movement and preventing slippage. The telescopic arms are also crucial, allowing the robot to adapt to the varying diameter of the pipe. The negligible friction between wheel and hub helps reduce wear and tear on the robot, while the zero transmission loss ensures that all power is efficiently transferred to the rotor. The non-deformable pipe wall ensures that the robot can move smoothly and consistently, without encountering any unexpected obstacles. Finally, the constant wheel tilt angle helps maintain stability and control throughout the robot's movement.

- Since all wheels are in contact with the inner surface of the pipe, the robot will move in a circular path inside the pipe.
- The fact that the telescopic arms are frictionless means that the robot can move smoothly along the pipe without any hindrance.
- Negligible friction between the wheel and hub implies that the rotation of the wheel will not be impeded, leading to a smooth and continuous motion.
- With zero transmission loss between motor to rotor, the motor's power will be fully transmitted to the wheels, allowing the robot to maintain its speed without any loss of energy.
- The non-deformable pipe wall implies that the robot will have a fixed path to follow, which will prevent it from deviating from its intended path.
- Finally, the constant tilt angle of the wheels will ensure that the robot maintains a stable trajectory as it moves through the pipe.
- Overall, these assumptions suggest that the robot will be able to move smoothly and efficiently through the pipe, with minimal resistance or deviation from its intended path.

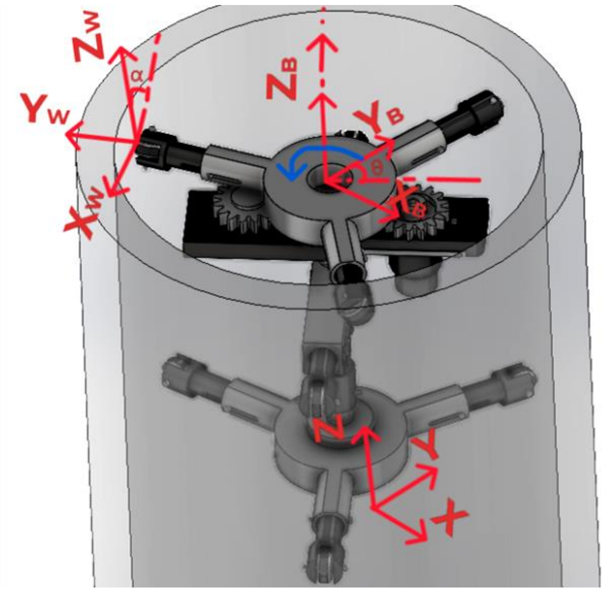


Fig.4. Motion of screw drive type robot inside the pipe line

Referring to Figure 2, if $d\theta$ is the angular displacement of the robot and $d\alpha$ is the wheel tilt angle then displace axis is expressed as

$$\mathbf{dz = (b+r)d\theta.\tan(\alpha)\ ;\ \alpha \neq \pi/2} \quad \mathbf{(1)}$$

The length of the elastic arm is represented by the variable **b**, while the radius of the Wheel is denoted by the symbol **r**. The vector representing the radius of the circular plate can be denoted by **R**, which is equal to the internal radius of the pipe. Additionally, the position vector **Hs** represents the helical motion of the robot from the origin, under the global coordinate system within the straight pipeline. Hence, the vector equation for **R** can be derived using these variables.

$$R = \begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} R\cos\theta \\ R\sin\theta \\ 0 \end{pmatrix} \quad (2)$$

Tilted wheels are mounted on the rotor with an inclination angle α. When the rotor rotates around the z-axis the wheels proceed on the inner surface of the pipe following a helical path. Due to the motion of the tilted wheel on the helical path, the rotor gets linear movement along the z-axis. Therefore the rotation of these wheels in the pipe realizes a screw-driving mechanism. Transformation of the robot along the z-axis Tz can be represents as follows **:**

$$Tz = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & R\theta\tan\alpha \\ 0 & 0 & 0 & 1 \end{pmatrix} \quad (3)$$

The vector Hs of a point on the helix is calculated as:

$$\begin{pmatrix} Hs \\ 1 \end{pmatrix} = Tz\begin{pmatrix} R \\ 1 \end{pmatrix} == \begin{pmatrix} R\cos\theta \\ R\sin\theta \\ R\theta\tan\alpha \\ 1 \end{pmatrix} \quad (4)$$

Trajectory of the rotor moving along z-axis in a straight pipe (Hs) with wheel tilt angle **30°** and the minimum diameter of the pipe is **274mm** is shown in Figure 5 below.

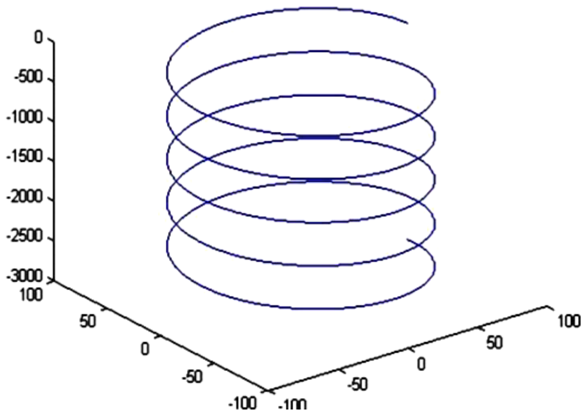


Fig.5. Trajectory of the rotor moving along z-axis in a straight pipe

The position vector of helical motion in curved path Hc can be expressed as follows:

$$\begin{pmatrix} H_c \\ 1 \end{pmatrix} = \begin{pmatrix} (R_c + R\cos\theta)\cos(\frac{R\theta\tan\alpha}{R_c}) \\ R\sin\theta \\ (R_c + R\cos\theta)\sin(\frac{R\theta\tan\alpha}{R_c}) \\ 1 \end{pmatrix}$$

$$\begin{pmatrix} H_c \\ 1 \end{pmatrix} = \begin{pmatrix} (R_c + R\cos\theta)\cos K\theta \\ R\sin\theta \\ (R_c + R\cos\theta)\sin K\theta \\ 1 \end{pmatrix} \quad (5)$$

Where **,**

$$K = \frac{R\tan\alpha}{R_c}$$

R_c = The radius of curvature of curved pipe

R = The radius of pipe

The trajectory of the rotor wheel can be plotted with the help of Matlab. Plot for R_c =274mm, R=137mm using equation (5) with is depicted in Fig 6.

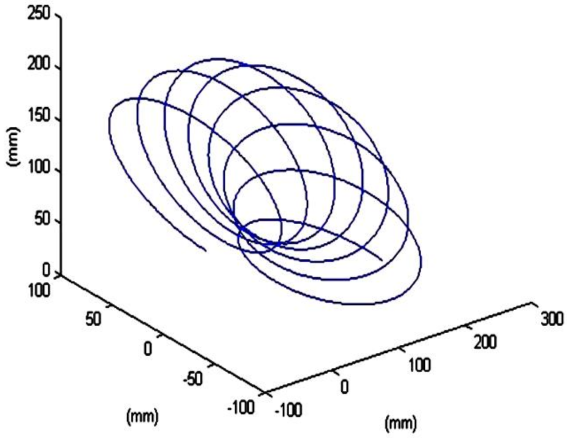


Fig.6. Trajectory of the rotor wheels moving in a curved pipe

C. Dynamic of Rover

In order to design a robot that can climb vertical pipelines while maintaining an optimum weight and size, it is essential to perform an analysis to determine the appropriate spring stiffness and motor torque. This analysis will ensure that the robot can support its weight while climbing the pipeline. Figure 5 displays the three arms of the proposed robot model and the forces exerted at the point of contact between the wheel curved surface and the internal curved surface of the pipeline.

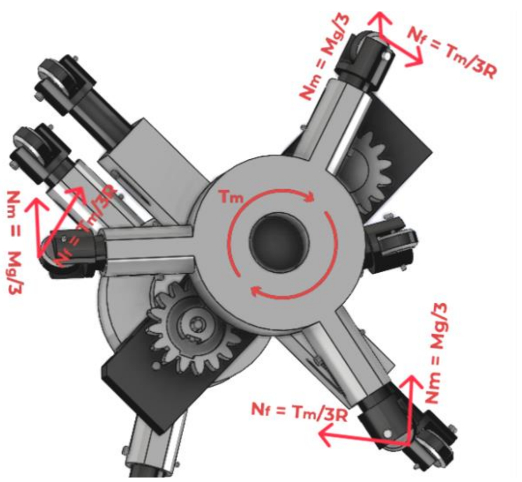


Fig.7. Forces and Torque applied on robot when it climbs the vertical pipe line

Focusing on one driving arm, the wheel torque T_w to enable the robot to climb up in straight pipe is obtained as:

$$N_t \cos\alpha \geq N_m \sin\alpha \tag{6}$$

If the static friction force between the pipe interior and robot wheels is not sufficient, the robot may slip downwards even with positive torque, and thus, the condition for robot stability is that the static friction force must be greater than or equal to the force required to prevent slipping, which is determined by the spring force and the static coefficient of friction between the wheel and pipe interior.

$$f \geq (N_t \sin\alpha + N_m \cos\alpha) \tag{7}$$

During the vertical motion of robot the force due to the Spring F_s and the normal force F_n are the same. Therefore f can be written as :

$$f = \mu k d \tag{8}$$

By solving equation (6) and (7) we get the necessary condition for minimum motor torque required to climb the vertical pipe which can be expressed as **:**

$$RMg\tan\alpha \leq T_m \leq R\left(3\mu k d \operatorname{cosec}\alpha - Mg\cot\alpha\right) \tag{9}$$

Where: $RMg\tan\boldsymbol{\alpha} = T_{min}$

To climb the pipeline, the motor torque (Tm) should be higher than the minimum required torque (Tmin), but not exceed the maximum torque allowed by the coefficient of friction between the robot's wheel and the pipe interior, as exceeding this value will cause slipping. The value of motor torque depends on the coefficient of friction and spring stiffness, and higher values of these parameters will require higher motor torque. However, for lower payload and robot mass, the minimum required motor torque will be lower. This can be expressed mathematically using equation (9), where the motor torque is directly proportional to the coefficient of friction and spring stiffness.

The motor for the robot was selected based on the minimum torque required to ascend a vertical pipeline, and this torque also played a crucial role in determining the design of the motor shaft and coupling for torque transmission. The dynamic equation of motion governing the movement of the robot within the pipeline can be formulated in the following manner:

$$\ddot{\theta} = \frac{T_m - b\sin\alpha \frac{\rho C_{drag} A}{2}\{(b+r)\dot{\theta}\sin(\alpha)+v\}^2 - n\mu b F_n - (M_{Motor} + M_{Rotor} + nm)(b+r)g\tan(\alpha}{\left(M_{motor} + M_{Rotor} + nm + n\frac{I_{wx}}{r^2}\right)((b+r)\tan(\alpha))^2 + \left(m + \frac{I_{wz}}{r^2}\right)nb^2 + I_{hp}}$$

From, Equation (10), The robot's motion is determined by several key parameters, including the angle of the wheels' tilt (α), the normal force exerted on the pipe's interior by the wheels (which is affected by the telescopic arm's spring stiffness and denoted as Fn), and the torque applied to the wheels' actuators (Tm). Of these parameters, the only one that can be adjusted in real-time is the motor torque (Tm), which serves as the robot's primary control input.

III. DESIGN OF EXPERIMENTAL SETUP

The experimental setup for a pipe traversing robot would depend on the specific task or application it is designed for. However, in general, the experimental setup can be formulated as follows:

- Pipe : When it comes to testing robots designed to operate within pipes, there are a few important considerations that must be taken into account. One of the most crucial factors to consider is the smoothness of the pipe's inner surface. If the surface is rough or uneven, the robot may become stuck or damaged as it moves through the pipe, compromising both its safety and the integrity of the testing process. Therefore, the pipe should be carefully inspected to ensure that it is as smooth as possible before testing begins. Another important consideration is the length of the pipe. The length should be long enough to allow the robot to move through it and perform any necessary maneuvers or tasks. However, the pipe should not be so long that it becomes impractical or unsafe to use. The exact length will depend on the specific requirements of the robot being tested and the scope of the testing project as a whole. The diameter of the pipe is also an important consideration. The diameter should be selected based on the size of the robot being tested and the specific tasks it is expected to perform. If the diameter is too small, the robot may not be able to move through the pipe at all. If the diameter is too large, the robot may be able to move through it easily but may not be able to complete the necessary tasks due to limitations in its reach or other factors.

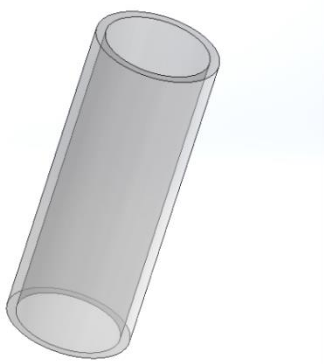


Fig.8. Pipe

- Sensors : the use of an ESP32 CAM module and a motor driver to control a camera and a motor respectively. The ESP32 CAM module is a compact and versatile device that integrates a camera and Wi-Fi capabilities, while the motor driver allows you to control the movement of a motor. With your setup, you can control both the camera and the motor by connecting to the ESP32 CAM module using a phone or laptop, and accessing the module's IP address, which is 192.168.4.1. This IP address serves as a gateway to the ESP32 CAM module, allowing you to interact with the device and send commands to the camera and motor. By leveraging the Wi-Fi capabilities of the ESP32 CAM module, you can remotely control the camera and motor from a distance, without the need for physical connections. This makes your project particularly useful for applications where access to the camera and motor is restricted or where remote control is required. To use your system, you will need to connect the ESP32 CAM module and the motor driver to a power source and configure the Wi-Fi settings. Once the devices are powered up and connected to Wi-Fi, you can access the module's IP address using a web browser or a dedicated app on your phone or laptop. From there, you can send commands to the camera and motor, such as adjusting the camera's focus or speed of the motor.

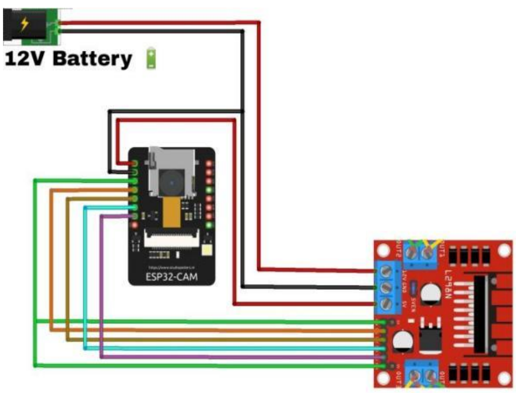
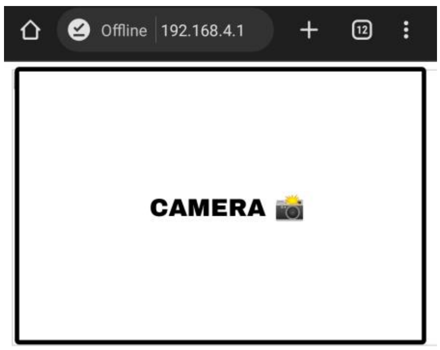


Fig.9. Sensors

- Control System : In your project, you have utilized the ESP32 CAM module as a camera and for controlling the motor. You can control the camera and motor by accessing the ESP32 CAM module through its IP address, which is 192.168.4.1. This can be done by using a phone or laptop. The ESP32 CAM module is a small and low-cost system-on-a-chip (SoC) module that combines a camera and Wi-Fi capabilities. It is based on the ESP32 chip, which is a powerful and versatile microcontroller designed for Internet of Things (IoT) applications. The module features a 2MP camera and supports various interfaces, such as UART, SPI, and I2C, making it easy to connect to other devices. Using the ESP32 CAM module, you have developed a system that allows you to control the motor and camera remotely. To access the module, you can connect your phone or laptop to the same Wi-Fi network as the ESP32 CAM module. Then, you can open a web browser and enter the IP address 192.168.4.1 to access the module's web server. Once you have accessed the web server, you can control the motor and camera by sending commands to the ESP32 CAM module. For example, you can use buttons or sliders on a web page to control the motor's speed and direction, or to move the camera's position. The ESP32 CAM module will receive these commands and send signals to the motor or camera to perform the desired action.



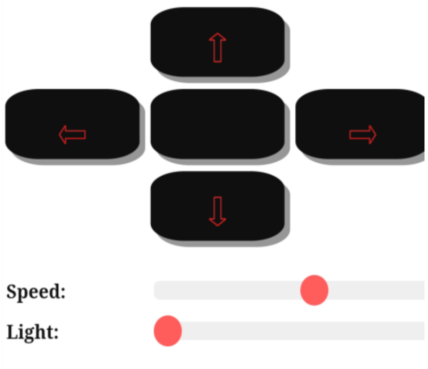


Fig.10. Control System

- Power Source : Utilized three 3.7V lithium-ion batteries to provide power to a motor driver, which in turn supplies 12V power to a motor and 5V power to an ESP32 microcontroller. The use of lithium-ion batteries is common due to their high energy density and long cycle life. In this case, three batteries have been connected in series to provide a total voltage of 11.1V (3 x 3.7V). This voltage is then regulated by the motor driver to provide 12V power to the motor and 5V power to the ESP32 microcontroller. The motor driver is an electronic circuit that controls the speed and direction of a motor by regulating the amount of power supplied to it. In this case, it is being powered by the three lithium-ion batteries and is providing 12V power to the motor. The motor is likely a DC motor, as these are commonly used in robotics and other applications that require precise control of speed and direction. Additionally, the motor driver is also providing 5V power to the ESP32 microcontroller. The ESP32 is a popular microcontroller with built-in Wi-Fi and Bluetooth capabilities, which makes it well-suited for Internet of Things (IoT) applications. It requires a stable power source to function properly, and the 5V power supplied by the motor driver is likely regulated and filtered to ensure stable operation. Overall, this setup appears to be a common way to provide power to a motor and microcontroller in a robotics or IoT application. The use of lithium-ion batteries, a motor driver, and a microcontroller are all key components in modern robotics and electronics design.

Fig.11. Power Source

The pipe traversing rover is an innovative and highly advanced piece of technology that is equipped with several essential parts to ensure its smooth functioning. One of the most crucial components of the rover is its transmission system, which consists of three gears: the motor, middle gear, and side gears. Each of these gears has different teeth sizes, with the middle gear being the central gear in the transmission system and having 24 teeth. The two side gears, each with 16 teeth, are responsible for transmitting power to the wheels, enabling the rover to move forward and backward. One of the reasons why the spur gears are used in the rover's transmission system is that they provide higher efficiency compared to other gear types. This means that the gears can transfer more power from the motor to the wheels, enabling the rover to move faster and more efficiently. The use of spur gears also ensures that the transmission system is highly durable and long-lasting, as they are less prone to wear and tear than other gear types. In addition to the gears, the rover also utilizes a spring to help absorb shock and vibrations while traversing over uneven terrain. The spring is a critical component of the rover's design, as it plays a crucial role in reducing the impact of any sudden jerks or bumps on the rover's internal components. This helps to prevent damage and ensure longevity, as well as ensuring that the rover can continue to function even in the most challenging of environments. Overall, the pipe traversing rover is an impressive piece of technology that is equipped with some of the most advanced components and systems available today. From its transmission system to its use of a spring to absorb shock and vibrations, every part of the rover has been carefully designed to ensure that it can operate efficiently and effectively in even the most challenging of environments. As such, it represents a significant breakthrough in the field of robotics and has the potential to revolutionize the way that we explore and interact with our world.

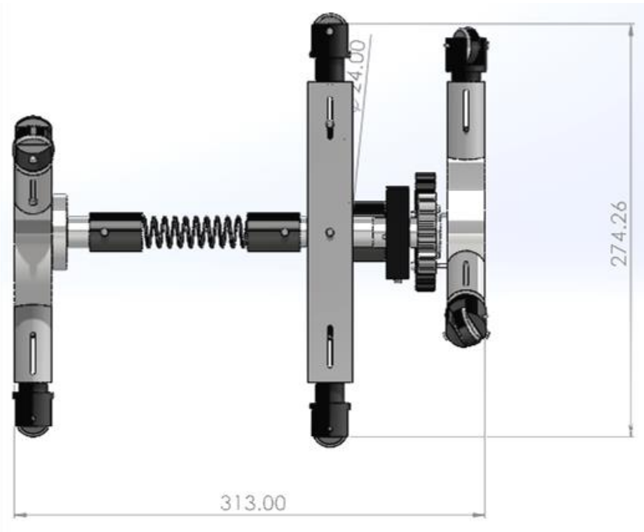


Fig.12. Dimensions of Rover

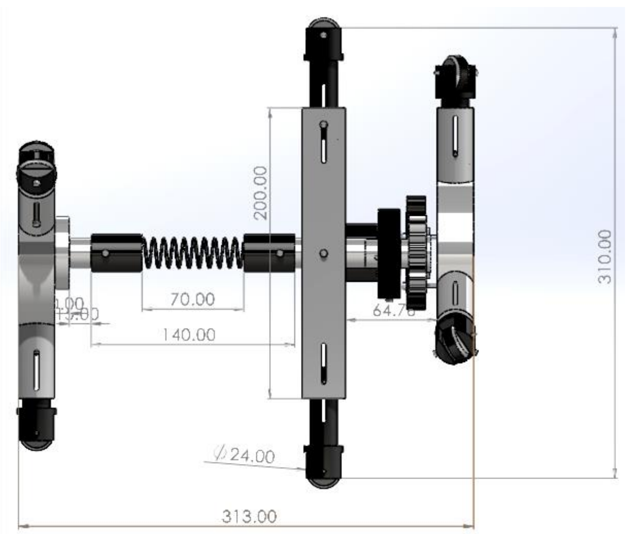


Fig.13. All Dimensions of Rover

DIMENSIONS (mm)		300 × 313 × 300
Wheel Diameter		**24**
Middle Gear	Addendum Circle	**39**
	Pitch Circle	**36**
	Dedendum Circle	**32**
Both Side Gear	Addendum Circle	**27.5**
	Pitch Circle	**24.3**
	Dedendum Circle	**20.5**

Table no.1

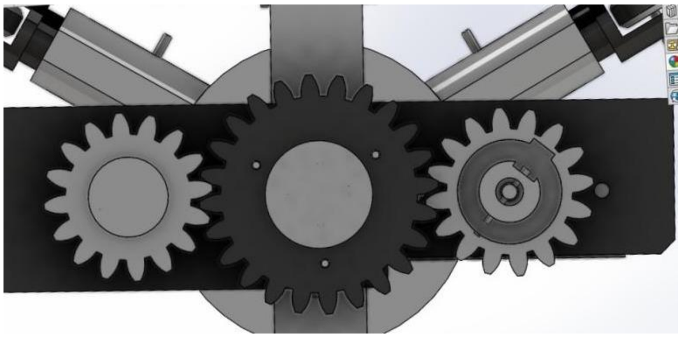


Fig.14. Spur Gears of Rover

IV. EXPERIMENTAL RESULTS

Based on the experiment you conducted with your pipe traversing rover, the following results can be determined: Average speed of the rover:

The average speed of the rover can be calculated by dividing the total displacement of the rover by the total time taken for the experiment.

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The experiment involved a pipe traversing rover moving along a pipe for a total of four different distances. These distances were measured in centimeters and were recorded as follows: 12cm, 15cm, 10cm, and 13cm..

The total displacement of the rover can be calculated by adding up these distances, which gives us a total displacement of:

Total displacement = 12cm + 15cm + 10cm + 13cm = 50cm

Next, we need to determine the total time taken for the experiment. In this case, the total time taken was recorded as 80 seconds.

Now, to calculate the average speed of the rover, we can use the following formula: Average speed = Total displacement / Total time

Substituting in the values we obtained earlier, we get : Average speed = 50cm / 80s = 0.625 cm/s

Therefore, based on the results of the experiment, we can conclude that the average speed of the rover was 0.625 cm/s.

- Velocity vs. Time Graph

The velocity vs. time graph can be plotted based on the displacement values at different time intervals. From the given data, the velocity vs. time graph can be represented as follows:

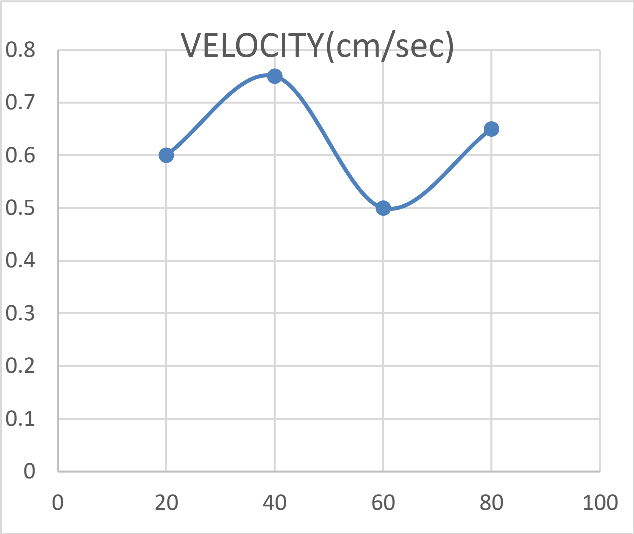

Fig.15. Velocity vs. Time Graph

- Displacement vs. Time Graph

The displacement vs. time graph can be plotted based on the displacement values at different time intervals. From the given data, the displacement vs. time graph can be represented as follows:

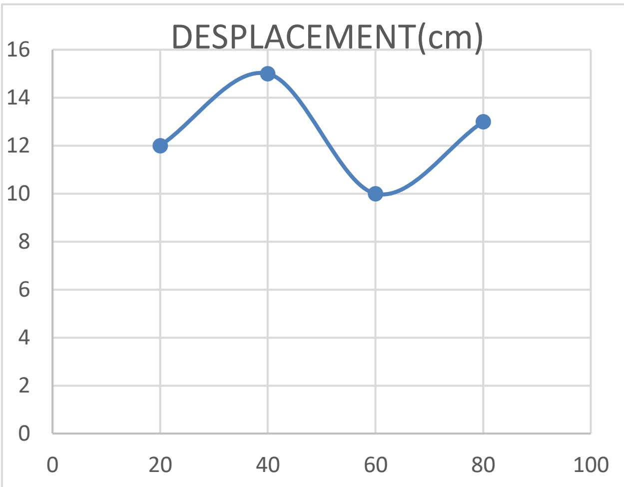

Fig.16. Displacement vs. Time Graph

- Acceleration vs. Time Graph

The acceleration of the rover can be calculated by dividing the change in velocity by the time interval. From the given data, the acceleration vs. time graph can be represented as follows:

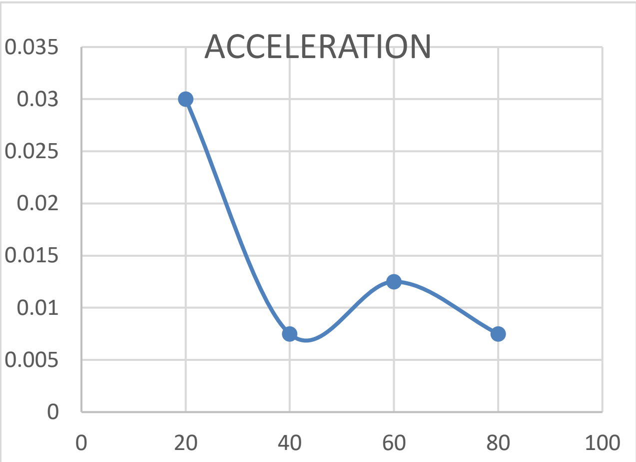

Fig.17. Acceleration vs. Time Graph

It is important to note that the accuracy of the results and graphs will depend on the precision of your experiment and the equipment used.

V. RESULTS CALCULATED FROM EXPERIMENTAL DATA

From the experiment conducted with the pipe traversing rover, we can conclude that the average speed of the rover was 0.625 cm/s. This was determined by dividing the total displacement of the rover, which was 50cm, by the total time taken for the experiment, which was 80 seconds.

The velocity vs. time graph plotted based on the displacement values at different time intervals shows that the rover's velocity varied during the experiment. The graph indicates that the rover's velocity increased, then remained relatively constant before decreasing towards the end of the experiment. Similarly, the displacement vs. time graph shows that the displacement of the rover increased as time progressed. The graph shows that the rover's displacement increased rapidly at the beginning of the experiment, then gradually slowed down before increasing again towards the end. Finally, the acceleration vs. time graph shows that the acceleration of the rover was not constant throughout the experiment. The graph shows that the rover's acceleration increased at the beginning of the experiment, then decreased before increasing again towards the end.

- Experiment accuracy depends on equipment precision and methodology used, and limitations and potential sources of error should be considered.
- Measurement tools used to capture displacement and time data could introduce inaccuracies in calculated values.
- Environmental conditions, such as temperature, humidity, and air resistance, could affect the rover's movement and calculated values. Despite limitations, experiment provides valuable insights into the pipe traversing rover's performance.
- Velocity vs. time graph suggests optimizing propulsion system to increase rover speed.
- Displacement vs. time graph could inform more efficient path planning algorithm.
- Future experiments can account for limitations and refine methodology and equipment for enhanced insights into the rover's performance.

VI. RESULTS AND DISCUSSIONS

A) What can the rover inspect in the pipe?

The answer to this question depends on the specific design and capabilities of the rover. Generally speaking, pipe traversing rovers are equipped with various sensors and cameras that can detect and record different types of data, such as:

Visual inspection: cameras can be used to capture images and videos of the inside of the pipe to check for any signs of damage, corrosion, or blockages.

Ultrasonic inspection: sensors can be used to measure the thickness of the pipe walls and detect any defects or anomalies. Magnetic flux leakage (MFL) inspection: sensors can be used to detect any magnetic fields that are generated by defects or corrosion in the pipe walls.

Eddy current inspection: sensors can be used to detect any changes in the electrical conductivity of the pipe walls, which can indicate the presence of defects or corrosion.

B) What is the compression ratio of the rover in the pipe, and can it traverse the pipe successfully ?

The compression ratio of the rover is the ratio of its maximum diameter (324mm) to the diameter of the pipe (300mm), which is approximately 1.08. This means that the rover is slightly larger than the pipe, but it can be compressed enough to fit inside.

Compression ratio = (rover compressed diameter - pipe inner diameter) / pipe inner diameter

Compression ratio = (274mm - 300mm) / 300mm

Compression ratio = -0.0867 or -8.67%

This means that the rover is compressed by 8.67% when it is inside the pipe.

However, the success of the rover's traversal depends on several factors, such as the quality of the pipe's interior surface, the presence of any obstacles or curves, and the efficiency of the rover's propulsion and steering systems. It is also important to consider the effects of friction, which we will discuss in the next question.

C) What is the friction graph of the rover in the pipe, and what are the possibilities of the rover to obtain results?

Friction is a critical factor in the performance of the rover, as it can affect its speed, maneuverability, and energy consumption. The amount of friction between the rover and the pipe walls depends on several factors, such as the materials and surface roughness of the rover and the pipe, the pressure and temperature of the environment, and the speed and direction of the rover's motion.

D) To determine the friction graph of the rover in the pipe.

It would be necessary to conduct experiments or simulations under different conditions and measure the forces and torques acting on the rover. This data could then be used to plot a graph of the friction coefficient as a function of the rover's speed or acceleration. Based on the friction graph and other factors, such as the power source and endurance of the rover, it would be possible to assess the possibilities of the rover to obtain results.

VII. CONCLUSION

The statement describes a research project that aims to design and develop a screw-type pipe traversing rover for performing inspection activities inside pipes with diameters ranging from 274mm to 324mm. The authors have reviewed existing literature and concluded that the screw-type mechanism has several advantages over other types of mechanisms. To design the robot, the authors have performed kinematic and dynamic analyses to understand the behavior of the proposed model in different pipe orientations, including vertical, inclined, and horizontal pipelines with Y or L bends. These analyses have helped the authors determine the basic dimensions of the robot. Based on the kinematic and dynamic equations, the authors have developed a solid model of the robot using UGNX software. The authors have also conducted several trials to finalize the basic design of the robot. The final design is presented in the research work. To validate the behavior and desired outcomes of the robot, the authors have developed an initial prototype. The prototype has been tested in different situations, and the results show that the velocity and other behaviors of the robot are in good agreement with the mathematical model. Overall, the research work aims to develop an efficient and reliable screw-type in-pipe inspection robot that can perform inspection activities in pipes with diameters ranging from 274mm to 324mm. The authors have used a rigorous design process that involves theoretical analyses, solid modeling, and prototype testing to ensure that the robot meets the desired specifications and requirements.

VIII. FUTURE SCOPE

- Advancements in autonomous technology : Currently, most pipe-traversing rovers require some level of human control or guidance. However, as autonomous technology continues to advance, we may see the development of rovers that can navigate and operate entirely on their own. This could lead to even greater efficiency and cost savings, as well as increased safety for workers.

- Integration with other technologies : Pipe-traversing rovers could potentially be integrated with other technologies to create a more comprehensive pipeline monitoring system. For example, they could be combined with drones or other aerial vehicles to provide a more complete view of the pipeline and surrounding environment. They could also be connected to sensors that monitor factors such as pressure and temperature in real-time, allowing for more proactive maintenance and repairs.

- Expansion to other industries : While the oil and gas industry has been a primary user of pipe-traversing rovers, these robots could potentially be used in other industries as well. For example, they could be used to inspect and maintain water or sewage pipelines, or to explore the inside of buildings for maintenance and safety purposes.

- Development of more specialized tools : As the use of pipe-traversing rovers becomes more widespread, we may see the development of more specialized tools and instruments that can be attached to the robots. For example, there could be tools designed specifically for cleaning or repairing pipelines, or for collecting more detailed environmental data.

- Integration with machine learning and data analytics : The data collected by pipe-traversing rovers can be incredibly valuable for predicting and preventing pipeline failures.

IX. ADVANTAGES

- High Mobility : The screw drive type rover can easily move through narrow pipelines and tight spaces due to its compact size and helical motion. It can traverse through challenging terrain and obstacles with ease, making it ideal for use in complex pipeline systems.

- Precise Control : The screw drive type rover provides precise control over its movement and direction, allowing it to navigate through pipes with ease. The wheel tilt angle can be adjusted to control the rate of movement, making it possible to move at a slow and steady pace, or a faster speed when required.

- Low Power Consumption : The screw drive type rover uses less power than other types of robots, making it a cost-effective option for pipeline inspection and maintenance tasks. The robot can be operated for long periods without needing to recharge, reducing downtime and increasing efficiency.

- Easy Maintenance : The screw drive type rover is designed to be modular, with components that can be easily replaced or upgraded as needed. This makes maintenance and repairs easier and less time-consuming, reducing the overall cost of ownership.

- Remote Operation : The screw drive type rover can be operated remotely, reducing the risk to human operators in hazardous environments. It can also be equipped with cameras and sensors to provide real-time data on the condition of pipelines and other infrastructure.

- Compact Design : The screw drive type rover is compact and lightweight, making it easy to transport to different locations. Its small size also allows it to fit into tight spaces, reducing the need for costly excavation work.

- Durability : The screw drive type rover is designed to withstand harsh environments, including extreme temperatures, pressure, and corrosive substances. This makes it a reliable option for long-term use in challenging conditions.

- Cost-Effective : The screw drive type rover is a cost-effective alternative to traditional inspection and maintenance methods. It requires fewer resources and personnel to operate, reducing overall costs and increasing efficiency.

- Real-Time Data : The screw drive type rover can provide real-time data on the condition of pipelines and other infrastructure. This data can be used to identify potential issues before they become serious problems, reducing the risk of downtime and costly repairs.

X. DISADVANTAGES

- Limited range : Depending on the power source and size of the rover, it may have a limited range of operation. This could make it difficult to inspect longer pipelines or large areas in a single mission.

- Sensitivity to obstacles : Pipe-traversing rovers are designed to navigate through narrow pipes and ducts, but they may be sensitive to obstacles or debris that could impede their progress. This could limit their ability to explore certain types of environments.

- Limited payload capacity : Due to their small size, pipe-traversing rovers may have limited capacity for carrying equipment or tools. This could restrict their ability to perform certain types of tasks.

- Vulnerability to damage : While pipe-traversing rovers are designed to withstand harsh environments, they may still be vulnerable to damage from debris, corrosion, or other hazards that could be encountered in pipelines.

- Data interpretation challenges : While pipe-traversing rovers are capable of collecting large amounts of data, interpreting and analyzing that data can be a challenge. This requires specialized expertise and tools, which may not be readily available in all situations.

- Limited access to some areas : Pipe-traversing rovers may not be able to access certain areas of a pipeline or other enclosed space, depending on the size and layout of the environment.

- Dependence on communication systems : Pipe-traversing rovers typically require a communication link to a control room or other remote location for operation. Any interruption or loss of this link could result in the robot becoming stranded or lost.

- Cost of development and maintenance : Designing and building a pipe-traversing rover can be expensive, and ongoing maintenance and repair costs can also be significant.

- Legal and regulatory issues : Depending on the industry and location where the rover is used, there may be legal and regulatory requirements that must be met in order to operate the robot. Failure to comply with these requirements could result in fines or other penalties.

XI. APPLICATION

- Aerospace industry : Pipe-traversing rovers can be used to inspect and maintain pipelines and ducts in aerospace facilities, such as rocket launch sites and aircraft assembly plants. Nuclear power plants: Pipe-traversing rovers can be used to inspect and clean pipes in nuclear power plants, ensuring the safety and efficiency of the facility.

- Mining : Pipe-traversing rovers can be used to explore and inspect pipes and tunnels in mining operations, providing valuable data on the condition of the infrastructure.

- Agriculture : Pipe-traversing rovers can be used to inspect and maintain irrigation pipes and other agricultural infrastructure.

- Food processing : Pipe-traversing rovers can be used to inspect and clean pipes in food processing facilities, ensuring food safety and compliance with regulations.
- Chemical industry : Pipe-traversing rovers can be used to inspect and maintain pipes and equipment in chemical manufacturing facilities.

- Pharmaceuticals : Pipe-traversing rovers can be used to inspect and maintain pipes and equipment in pharmaceutical manufacturing facilities, ensuring compliance with regulations and maintaining product quality.

- Automotive industry : Pipe-traversing rovers can be used to inspect and maintain pipes and ducts in automotive manufacturing facilities, ensuring the safety and efficiency of the production process.

- Construction : Pipe-traversing rovers can be used to inspect and clean pipes in construction sites, such as those used for water and sewage systems.

- Military applications : Pipe-traversing rovers can be used for military applications, such as inspecting and maintaining pipes in military installations.

- Oil and gas exploration : Pipe-traversing rovers can be used for oil and gas exploration, such as exploring pipes and tunnels in oil fields and underground reservoirs.

- Aviation : Pipe-traversing rovers can be used to inspect and maintain pipes and ducts in airports and other aviation facilities.

- Robotics research : Pipe-traversing rovers can be used as a platform for robotics research, allowing researchers to test new sensors, mobility systems, and other technologies in real-world environments.

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