Project Description

1. **Title:** Design and Development of a Screw Drive Type Wheeled Snake-like Robot to Access the inaccessible Areas inside the Boiler Tubes and other Enclosures.

   Institute: Indian Institute of Technology (IIT) Bhubaneswar

2. **Aim / Objectives:**

- To design a snake like robotic configuration that can move inside the enclosed inaccessible areas in boilers such as boiler tubes for inspection during preventive maintenance period.
- To design and analyze various locomotion patterns of the proposed robot for various scenarios, such as vertical piping, horizontal piping, pipe bends and sloping pipes in piping sections.
- To develop a suitable control scheme that allow smooth motion of the snake-like robot, while moving on the above-mentioned intricate surfaces.
- Testing and experiments with hardware in the laboratory set-up
- To analyze the data collected using the vision system mounted on the robot for the damage happened to the inner surface of the pipe.

3. **Executive Summary (*One page*):**

Industrial systems such as boilers, heat exchangers, and pipelines require periodic inspection to ensure safe and efficient operation. Many of these systems contain **narrow tubes with diameters as small as 5 cm**, making inspection extremely difficult using conventional methods. Manual inspection in such confined environments is often unsafe, time-consuming, and sometimes impossible without dismantling equipment.

This project proposes the **design and development of a screw-drive type wheeled snake-like robot specifically designed for navigation inside 5 cm diameter pipes**. The robot is inspired by the flexible motion of snake-like robots, allowing it to manoeuvre through narrow cylindrical spaces while maintaining stable locomotion by holding the inner surface of the pipe. The screw-drive assisted wheeled mechanism provide motion in helical manner within the tube.

The robot will be designed with **compact dimensions, lightweight structure, and modular sections** to allow smooth movement inside narrow pipes. The system may also integrate a **camera module for visual inspection**, enabling operators to monitor internal pipe conditions and detect defects such as corrosion, cracks, or blockages.

The development process includes **concept design, CAD modelling, mechanical fabrication, and experimental validation** of the robot in a simulated pipe environment. The ultimate goal of this project is to develop a robotic inspection system that can access areas that are otherwise difficult or dangerous for human workers to reach.

3.1. Methodology:

A three-dimensional CAD model of the Screw Drive type snake-like Robot prototype design has been created after assessing various existing designs. It was decided to incorporate two major degrees of freedom like translation along with rotation of the robot as well as length adjustments (like compression and expansion of spring mounted hand) to incorporate a certain range of movement by holding the surface of the pipe. For simplifying the assembly of components in Sledworks, and Matlab software used and for simulation also, the design has been limited to being conceptual. stress-strain analysis has been carried out for the spring and spring mounted hand of the Screw Drive-type Snake-like Robot structure to assure the structural integrity of the design before implementation into fabrication. Since ductile material was selected and the structure was subjected to loading by thinking about the reaction force consideration by the wall of the pipe to the spring mounted hand. Based on the numerical results, the weakest locations of the Snake Robot are identified. Since the design consists of an assembly of multiple links, a transient structural analysis was also performed with the help of the multi-Parts-body module in Solid-works. Design for manufacturing and assembly (DFMA) has been completed after consideration of results. Helical Motion of the Screw Drive-type Snake like Robot captured by using the 3-12volts stepper Motor with encoder. The control strategy on the basic level would be based on commutation with the Motor-Encoder by programming the PWM signals on the Raspberry pi zero 2w controller along with a 5MP variable focus camera module has been carried-out to take live feed, powered and controlled with Raspberry pi zero2w so that the live feed which has been taken visualized on screen by IOT based control, as well as ultrasonic sensors are also being observed to measure the thickness of the pipe sections.

3.2. Research Achievements:

The components used for DFMA are standard components available easily and differ from the conceptual design. However, the components have been selected such that the overall structure remains the same as in the conceptual design keeping in mind the easy availability and easy manufacturing of parts. The design is shown in the following **figure1**.

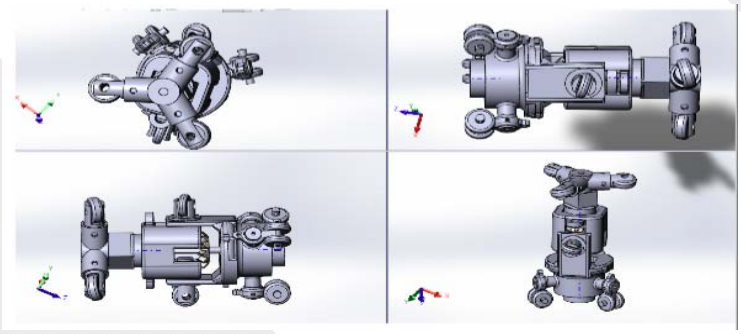

Figure1.ConceptualDesign with four different views (FV, LV, RV, TV)

3.3. The Kinetic simulations cases used were:

1. The Screw Drive Snake-like Robot going inside the pipe in helical manner is shown in the **Figure2**.
2. Spring stiffness has been calculated by applying load.
3. The Robot will travel inside the pipe by holding the inside surface of the pipe.
4. Stress and strain analysis showing the results **figure3**.

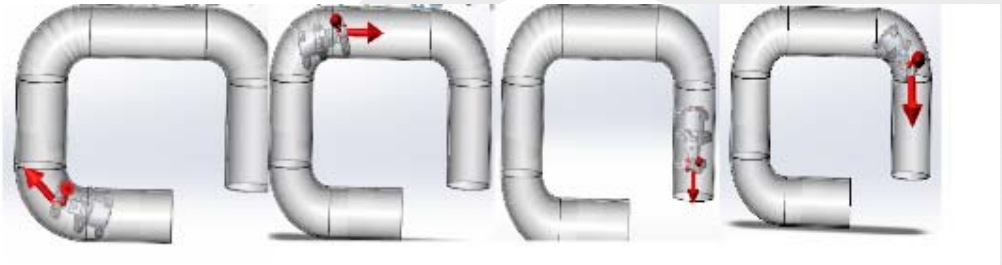

Figure2. Moving robot into the different section of the pipe.

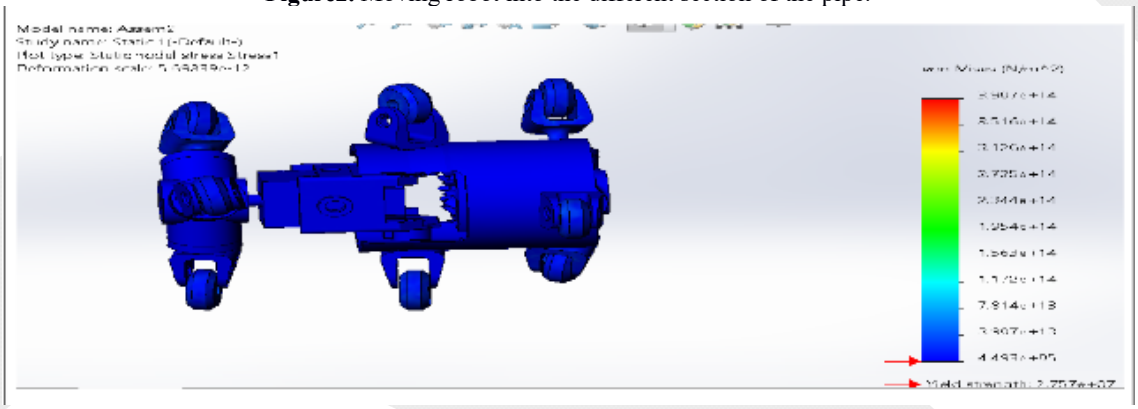

Figure 3. Kinematics analysis of the Robot

3.4. Hardware platform setup for Robot:

An acrylic Tube of ID 50mm and OD 60mm has been mounted on horizontally placed wooden board with the help of clamps tightly. Robot must travel from each section of the tube and that section has been made with elbow and t-joints of the pipe and rigidity of the hardware setup is considered very carefully, **figure4** shows the hardware platform setup.

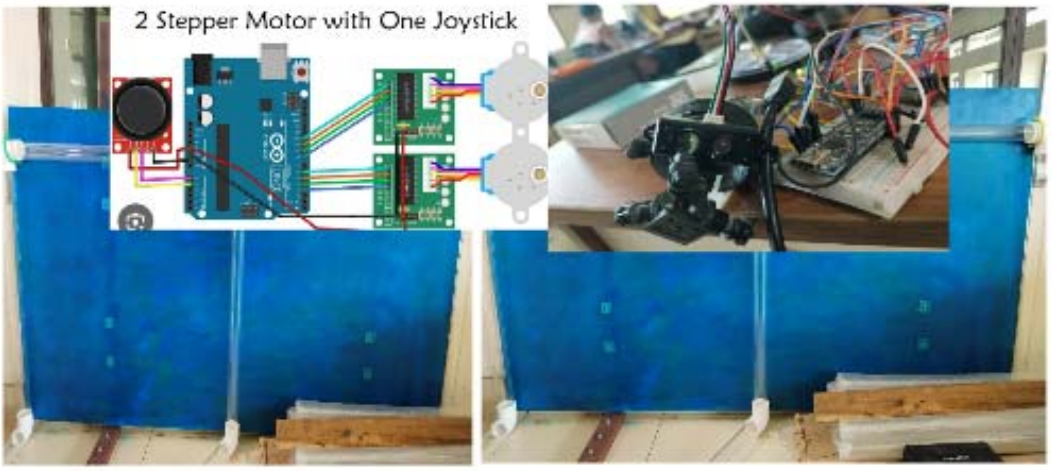

Figure4. Hardware Setup with acrylic tube

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Here the assembly and experiments of the robots has been conducted very carefully, experiments inside the pipe CW and CCW with the help of Joysticks with mounted lider sensor, analytical data achieved by it can be seen on OLED to measures the unevenness of inside the pipe surface.

Figure5. Travelling of robot in 50mm dia. pipe remotely along with lider sensor.

Testing for measures that is maneuvering of Screw drive type-wheeled-snake like robot into vertically upward and downward inside the acrylic tube, but due to non- slipping surface condition of acrylic tube, we are facing difficulties therefore we required mild-steel pipe of 50mm inner diameter to conduct experiment but due to unavailability of pipe experiment stuck at last stage.

4. Scope for further work

Although the current project focuses on developing a robotic system capable of navigating inside **5 cm diameter pipes**, several improvements and extensions can be explored in future research.

Future work may include **integration of advanced sensing technologies**, such as ultrasonic sensors, thermal sensors, or laser scanners, to detect structural defects inside

pipes. These sensors can enable the robot to perform detailed inspections and identify corrosion, cracks, or leakage points.

Another potential development is the **implementation of wireless communication and remote monitoring systems**, allowing operators to control the robot and receive real-time inspection data from a safe location.

Further improvements can also be made in the **locomotion mechanism**, enabling the robot to navigate through complex pipe geometries such as bends, vertical sections, or varying pipe diameters. Additionally, incorporating **autonomous navigation algorithms and intelligent control systems** could allow the robot to move automatically inside pipes and avoid obstacles.

With these enhancements, the robotic system could evolve into a **fully autonomous pipe inspection robot capable of performing advanced maintenance and monitoring tasks in industrial environments**.

5. Benefits visualized

The proposed robotic system offers several important benefits for industrial inspection and maintenance operations.

- Firstly, the robot improves **safety by eliminating the need for human workers to enter hazardous and confined spaces** such as boiler tubes or narrow pipelines.
- Secondly, the system can **perform inspection inside 5 cm diameter pipes that are otherwise inaccessible using conventional tools**, enabling efficient monitoring of internal pipe conditions.
- The robot also allows **real-time visual inspection using an on-board camera**, which can help identify defects such as corrosion, cracks, blockages, or structural damage.
- Another advantage is the **reduction of maintenance time and operational downtime**, as the robot can quickly navigate through narrow tubes and provide inspection data without requiring disassembly of equipment.
- Furthermore, the compact and modular design makes the robot **adaptable for different industrial applications**, including inspection of boiler tubes, heat exchanger tubes, pipelines, and other confined enclosures.
- Overall, the proposed system can contribute to **safer, faster, and more efficient industrial inspection processes**.