CHAPTER 7

FLEX-INSPECT ROBOTIC SYSTEM FOR PIPELINE EVALUATION

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7.1 INTRODUCTION

Pipelines are vital infrastructures that function as the backbone of various industries. These include oil and gas, water supply, and chemical processing pipelines. These extensive networks of pipes are designed to transport fluids from crude oil and natural gas to filtered water and hazardous chemicals over considerable distances efficiently and safely. The importance of pipelines is endless, as they enable the transportation of critical resources that support communities and stimulate global economies.

Pipelines are important for our industry, especially for hydrocarbon extraction, transportation, and distribution in the oil and gas sector. The United States Energy Information Administration states that pipelines represent roughly 70% of the transportation of crude oil and refined products in the United States, highlighting their vital role in ensuring energy security (Hernandez et al., 2025). The construction and maintenance of these pipeline systems pose significant hazards like leaks and bursts; hence, formulating and adhering to engineering standards and regulatory measures lowers the chances of these happening. In addition, regarding water supply, pipelines play a significant role in transporting drinkable water to the citizens of both urban and rural areas. In the

chemical processing industry, many substances, such as acids, solvents, and other hazardous materials, are transported through pipelines. The design and operation of these pipelines must follow strict safety regulations to prevent accidents and ensure smooth operations (Zhang et al., 2023).

Pipelines are among the most economical methods for transporting gas, liquids, oil, water, and sewage. However, they face continuous aging and damage issues, making periodic inspections crucial to prevent environmental harm and financial losses (Wang et al., 2024). Pipelines often operate in challenging environments, which makes manual inspections difficult, costly, and sometimes impossible.

Their location and structure further complicate pipeline inspection. Many pipelines are underground, underwater, or in confined spaces that are too narrow or hazardous for humans to access. Tiny spaces could cause significant difficulties for human inspection, as these areas often lack sufficient room for movement or carrying equipment (Chen et al., 2024). Furthermore, these environments may be risky due to exposure to toxic substances, insufficient oxygen levels, or structural instability. These challenges demand innovative solutions to ensure safety and efficiency.

Hence, the emergence of robotic solutions has revolutionised pipeline inspection, offering automated and efficient methods to detect issues such as corrosion and blockages. In-pipe Inspection Robots (IPIRs) have emerged as a practical solution to automate these processes, ensuring safety, efficiency, and accuracy (Nguyen et al., 2025). While earlier inspection robots, such as the MAKRO and KAIRO series by inspector systems, required forward and backward movements for navigation, researchers identified that holonomic rolling movement could allow quicker adaptation to winding pipes (Tan et al., 2024).

Building on previous designs, including their first-generation pipeline inspection robots, engineers have implemented spring joints to achieve higher flexibility with fewer actuators. These advancements enhance the robots' ability to navigate complex pipeline systems while reducing mechanical complexity, making them more efficient and versatile.

Therefore, this study's proposed solution is FLEX-INSPECT: An articulated robotic system for efficient pipeline and tight space

inspection. This system combines previous research into one (IPIRs) that connects advanced movement with a compact design to address the challenges of inspecting pipelines and confined spaces. FLEX-INSPECT aims to set a new standard for adaptability in environments where traditional inspection methods fall short.

7.2 FLEX-INSPECT ROBOT DESIGN

The project workflow for developing the proposed robot, FLEX-INSPECT, has been structured into two phases of research and development of the compact pipe inspection robot. The first phase of the workflow will include the identification and finalisation of the project title, reviewing related works to establish the fundamentals of the project's requirements and capabilities, outlining the robot's structural and functional components for the robot's system architecture, identifying the suitable hardware to be used based on the literature review, testing and incorporating the critical sensors for the inspection and developing a Computer Aided Design (CAD) model for the chassis of the robot. After that, the second phase of the project will start with integrating all the components into the physical structure and conducting a thorough functionality test in controlled environments like dry, wet, and tight space conditions.

The project methodology focused on designing a compact and cost-effective articulated robotic system that meets the project's objectives. The methodology will emphasise system initialisation, navigating, obstacle avoidance, data collection, real-time monitoring and control, the feedback mechanism, and environment testing and validation.

The project starts with system initialisation, establishing the primary connection between all the system's essential components (Figure 7.1). This includes connecting the central controller to the sensors, actuators, and the controller. Raspberry Pi has been chosen as the robot's microprocessor, serving as the robot's brain and coordinating all the hardware and software elements of the project.