DEVELOPMENT OF LINKAGE MECHANISM FOR IN-PIPE ROBOT

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DECLARATION

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LIST OF ABBREVIATIONS

AC	Alternating Current
CAD	Computer Aided Design
DC	Direct Current
IC	Integrated Circuit
ICSP	In-Circuit Serial Programming
PIG	Pipe Inspection Gauge
PWM	Pulse Width Modulation
SPP	Serial Port Protocol
USB	Universal Serial Bus
USM	Universiti Sains Malaysia
3D	3 Dimensional

DEVELOPMENT OF LINKAGE MECHANISM FOR IN-PIPE ROBOT

ABSTRAK

Kerja pemeriksaan di dalam saluran paip telah dilakukan oleh manusia untuk memerhati dan menetusahkan mana-mana kebocoran terutamanya di dalam industri loji, bahan kimia, gas semula jadi dan pelantar minyak. Persekitaran kerja ini adalah sangat berbahaya dan berkemungkinan besar memberi bahaya kepada pekerja sama ada kesan jangka masa pendek atau panjang. Untuk menyelesaikan masalah ini, robot pemeriksa dalam paip telah diperkenalkan bagi menggantikan kerja ini dan berevolusi untuk menawarkan prestasi yang lebih baik berbanding dengan kerja pemeriksaan secara manual. Tujuan projek ini adalah untuk merekabentuk robot pemeriksa dalam paip yang berkebolehan untuk bergerak dalam paip and membelok dalam keadaan stabil tanpa haus dan lusuh di penjuru paip yang mempunyai pelbagai diameter di pasaran dan juga industri. Rekabentuk robot termasuk bagaimana untuk membelok di sudut paip dan luas permukaan yang bersentuhan bagi robot untuk memastikan robot sentiasa stabil apabila bergerak menyelusuri saluran paip. Untuk memastikan mobiliti robot di dalam saluran paip, sistem kawalan telah digunakan pada badan robot untuk memusingkan tayar menggunakan Arduino UNO sebagai “minda” yang menyalurkan elektrik kepada sistem lokomotif robot.

DEVELOPMENT OF LINKAGE MECHANISM FOR IN-PIPE ROBOT

ABSTRACT

Humans have carried out pipeline inspection work to watch for and find any leaks, particularly in industrial facilities, chemical plants, natural gas pipelines, and oil rigs. This workplace is the most hazardous and has a high likelihood of endangering employees in the short or long term. In order to solve this issue, in-pipe inspection robots have been developed to take the position of workers and have improved performance over manual inspection. The goal of this project is to create an in-pipe robot capable of turning in a steady manner at pipe junctions of varying diameters found in commerce and industry. Robot design, including turning mechanism for pipe corner and surrounding area. The purpose of this project is to design an in-pipe robot which is capable to move in the pipe and turning in stable condition without wear and tear problem in the pipe junction with various diameter in the market and industry. The robot's design includes a mechanism for turning around a pipe corner and a point of contact to keep the robot stable as it travels through the pipeline. Using Arduino UNO as the robot's "brain" to transfer electrical supply to its locomotion, a control system is constructed in the robot's body to rotate the wheels and make it mobile in the pipeline.

CHAPTER 1
INTRODUCTION

1.1 Overview of Project

For the ecology and society, pipeline infrastructure is crucial. The goal of constructing a pipeline is to transfer water, natural gas, chemicals, and oil, however its biggest drawback is leaking. To prevent pipeline leaks, an in-pipe robot is therefore the ideal option instead of a human to check the pipe's condition. Not only are finances involved in the pipeline leakage problem, but also human safety, the environment, sustainability, and health.[1]

There are many different types and sizes of piping available today. The connection types, such as T-shape, L-shape, curved radius pipe, and S-shape pipe, may be in either a vertical or horizontal position. Designing an in-pipe robot that can travel within the specified pipeline connection is a problem for researchers.

The robot can be classified into two types of locomotion which is the active locomotion and passive locomotion. Active locomotion means the robot can move in the pipeline actively and accurately controls the speed as well as the direction by carrying drive source. While the passive wheels mean the robot is having difficulties to control their speed and area because disability in controlled movement. In-pipe robot with passive locomotion moving due to the flow of the liquid inside the pipe.[2]

There are numerous in-pipe robots being developed and sold today, including the Pipe Inspection Gauge (PIG), wheeled robots, caterpillar robots, wall-pressed robots, walking robots, and screw robots. Each robot has advantages and downsides. For instance, the PIG type robot relies solely on the flow of the pipe and is not powered by any engine. Although the driving mechanism of the in-pipe robot still needs to be explored to see whether the speed of the motor can be applied in all types of robots, the disadvantage of the caterpillar type robot is that it is unable to climb up the vertical pipeline.[2]

1.2 Project Background

A pipeline-moving robot called an "in-pipe robot" is made for inspection duties. By using this technology, it is simpler for humans to identify the pipeline leak's location and to take fast action to stop any environmental problems. For instance, any leakage of chemicals or oil will have an impact on the ecosystem, especially since water is a vital resource for humans.[2]

Additionally, it will be more challenging to respond to a natural disaster if the pipeline damage is not promptly corrected because it will be challenging to pinpoint the exact area of the defect's origin. The in-pipe robot is the most cost-effective approach to perform any inspection job within the pipeline because installing sensors along pipelines would be too expensive. Robots have the advantage of being able to operate through pipes with diameters ranging from 184.34mm to 224.06mm while performing dangerous tasks and lowering labour costs. By understanding the optimal approach for the robot to move and adapt with various sizes of pipeline, research of its mechanism is important.

The use of in-pipe robots will then be a substitute for people performing tasks within pipelines that could be hazardous to their health and safety. A little spark can start a huge fire in a chemical substances facility, making working in hazardous environments like chemical pipelines more likely to put workers in danger. The in-pipe robot's drive mechanism, control interface design, electrical wiring, shape and weight distribution, and programming all need to be studied. The design of the in-pipe robot also includes programming. Each element of the design will have an impact on the robot's functionality and dependability.

In the previous project, the robot's design was built on a triangle, with wheels on each of its edges serving as the robot's driving force[3]. When the robot turns in a T-pipe, one of the limitations that can be noted in earlier projects is that the wheel's ball joint is not stable enough to hang on to the pipe wall, leading to wear and tear issues at the wheel.

1.3 Problem Statement

There are various issues that need to be resolved based on prior research on in-pipe robots [3]. Since the front ball wheels are not in contact with the pipe wall, there will be more friction on the wheels, making it more difficult for the robot to move correctly. This contributes to the wheel's wear and tear issue as well. Therefore, the major goal of the current article is to create a mechanism for a robot that would increase the stability of the front wheel and decrease wear and tear issues.

1.4 Objectives

The purpose of this project is to figure out an efficient way for in-pipe climbing and effectively performing diagnostics and various other tasks inside of a pipe using robotics. The project is carried out with objectives:

i. To improve the stability of in-pipe robot when turning in the T-shape or bend pipe.
ii. To overcome the wear and tear problem at the ball joint of wheel.
iii. To make an adaptive robotic design to adjust it according to the pipeline parameters.

1.5 Scope of Project

The project scope will be shown in the Table 1.1:

Table 1-1 : Project Scope and Description

Scope	Description
Identify the problem	• Having a general understanding of how things are. • Read the project-related literature review. • Discover the significance of the in-pipe robot's usage.
Analysis of the current in-pipe robot concept	• Analyse the several types of in-pipe robots that are currently in use. • Determine the robot's limitations currently available. • Study the robot's mechanics.
Design of the in-pipe robot	• Create a 3-D model of a robot using sketches. • Design the free-moving locomotive robot. • Calculate the necessary force for the linked action.
Prototype fabrication and cost estimation	• Build a prototype. • Cost calculation for the fabrication of prototype.
Experiment / Testing	• Testing the prototype. • Analyse the function.
Analysis of result	• Analyse the robot. • Identify future work.

CHAPTER 2
LITERATURE REVIEW

2.1 Overview

This literature review discusses about the existing in-pipe robots that had been researched and developed besides the type of in-pipe robot, the existing moving mechanism and the mechanism that attach to the wall are discussed.

2.2 Types of In-pipe Robot

The in-pipe robot that exists today was created to perform duties that are too risky for people to handle. For a long time, researchers tried to create a mechanism for the robot to perform inspection job by initially mimicking animal locomotion; however, later, rotating, and wheeled inspection robots were the result of this evolution [4].

2.2.1 Pipe Inspection Gauge

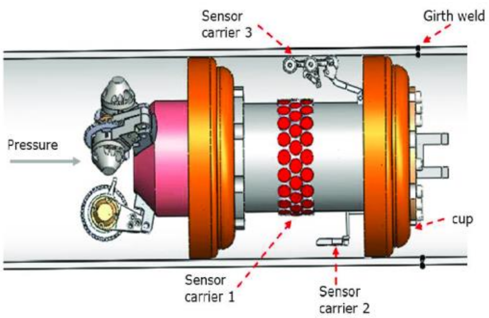

Figure 2-1 : Pipe Inspection Gauge (PIG)

This Pipe Inspection Gauge in-pipe robot in Figure 2-1 has advantage of moving without actuator. It drives with the help of force from the fluid or gas pressure to make it move. The disadvantage of this robot is difficult to control the speed because it depends on the speed of fluid and gas through the pipeline and when in junction. [5][6][7][8]

2.2.2 Wheeled Type In-Pipe Robot

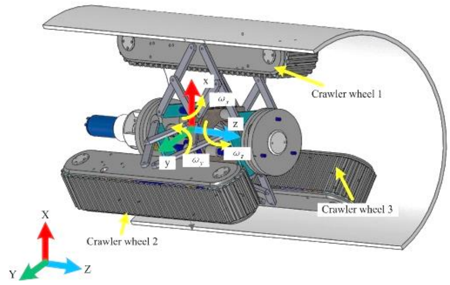

Figure 2-2 : Wheel Type In-Pipe Robot

In Figure 2-2, this Wheeled Type In-Pipe Robot is built with the simple design and able to steer but this type of robot only used for horizontally pipelines. The disadvantage of this robot is the possibility to slipping when climb up to the steeper or vertical pipeline. [5][6][7][8]

2.2.3 Caterpillar Type In-Pipe Robot

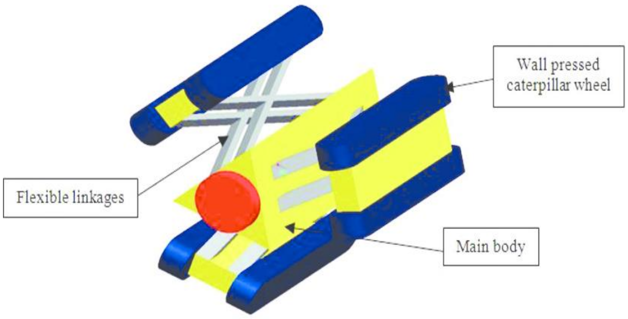

Figure 2-3 : Caterpillar Type In-Pipe Robot

The Caterpillar Type In-Pipe Robot's mechanism is essentially identical to that of the Wheeled Type In-Pipe Robot, and it is capable of operating in horizontal pipes. The robot can adapt to complicated pipe conditions thanks to the wall-pressed system. Caterpillar wheels serve as the caterpillar system's good traction force for forward and reverse motion.

2.2.4 Wall Pressing Type In-Pipe Robot

Figure 2-4 : Wall Pressing type In-Pipe Robot

A wall pressing type in-pipe robot that may be utilised for both horizontal and vertical pipeline is shown in Figure 2-4. The robot includes flexible connections that can be fastened to the pipe wall in order to prevent slippage in vertical pipes. [5][6][7][8]

2.2.5 Walking Type In-Pipe Robot

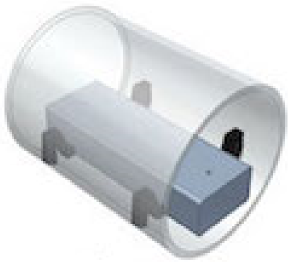

Figure 2-5 : Walking Type In-Pipe Robot

Less expertise is available in the market for walking type in-pipe robots. This is because the robot's numerous actuators make its system challenging to manage. The robot's design is intricate, necessitating careful development and experience in order to create and control the robot. [5][6][7][8]

2.2.6 Worm Type In-Pipe Robot

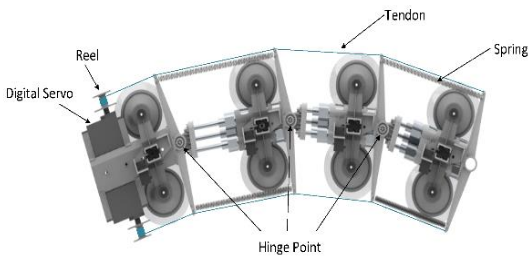

Figure 2-6 : Worm Type In-Pipe Robot

In-Pipe Worm Type Robot will move through the pipeline like an inchworm, with the front section moving first and the back part following. The robot's body will expand and contract sequentially to move forward and backward using a mechanism similar to a transverse wave. This robot is preferred for pipes with tiny diameters; however, it often moves more slowly. [5][6][7][8]

2.2.7 Plastic Elastic Joint Pipeline Inspection Robot

Figure 2-7 : Plastic Elastic Joint Pipeline Inspection Robot

Plastic Elastic Joint Pipeline Inspection Robot consists of four links, and they are connected by three spring joints. The rear rolling and driving units and the front rolling and driving units are, respectively, symmetrical. When travelling along the pipe axis, the hemispherical wheels do not spin around the roll-axis via reaction force. Due to the angle of the rolling motor, which can be changed by an absolute encoder attached to the motor's back, it can move down a vertical pipe [4].

2.2.8 Propeller Type In-Pipe Robot

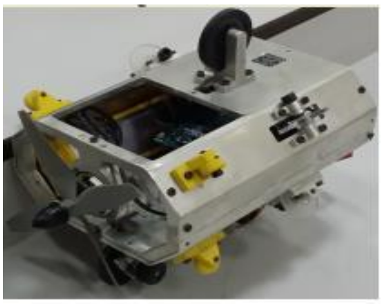

Figure 2-8 : Propeller Type In-Pipe Robot

This Propeller Type In-Pipe Robot's mechanical design satisfies important requirements, including constant ability to travel through a pipeline with elbows and retain adequate contact with the inner surface of the pipe in addition to sturdy and lightweight construction. To make it simple to disassemble during testing, the robot's aluminium chassis is constructed using two sheets that are screwed together. Six wheels are in contact with the inside surface of the pipe to ensure the robot maintains smooth motion and avoids any edges of the robot from running into the pipeline [9].

2.2.9 One-Inch Pipe Inspection Robot

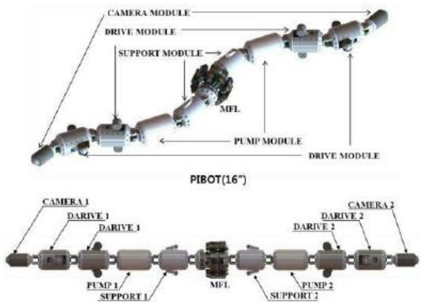

Figure 2-9 : One-Inch Pipe Inspection Robot

It is proposed to use a flexible, active-traction inchworm robot for the one-inch pipe inspection robot (PI-RO I). Robots that actively output propulsive and traction forces as a means of increasing both forces are known as active force generators. This mechanism requires the development of an extension unit for propulsion and traction as well as a grip device to retain the robot inside the pipe. This robot was made to examine the underground water and gas pipes that feed residences. This robot travels forward by repeatedly performing the motions that hold the pipe in its grip unit in front of the axial extension actuator. Additionally, when pressure is applied to the structure grasp unit, the front extension unit extends and the rubber tube expands, holding the robot inside the pipe.

2.2.10 In-Pipe Robot with Underactuated Twisting Joint

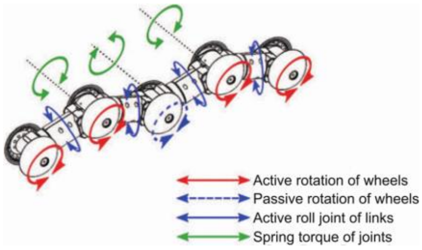

Figure 2-10 : In-Pipe Robot with Underactuated Twisting Joint

Both active and passive rotational degrees of freedom are used to create underactuated twisting joints. Three elastic joints that are passively bent by torsion springs make up the robot. To prevent the robot from falling down a vertical pipe, the springs push all wheels firmly against the pipe's inner surface. Unlike the previously produced robot, the new mechanism may rotate its body like a helix to change the orientation around the pipe axis [4], [10]. Each link has a DC geared motor fitted (housing). Each link consists of two rotating, bearing-supported sections that can move in relation to one another [11]

2.2.11 Reviews on Type of In-Pipe Robot

Table 2-1 : Reviews on Various Type of In-Pipe Robot [12]

Configuration	**Inspection Application**					**Advantages**	**Disadvantages**
	Flaws	**Corrosion**	**Pain thickness**	**Visual inspection**	**Type of cleaning**		
Wheel type	☑	☒	☒	☑	Brushes	The design of the robot is very simple. The use of sensors and cleaning devices makes the robot to inspect and clean the pipe in better way.	The wheel may not be able to give the sufficient friction to move inside the pipe. The wheels may dislocate its position when cleaning operation performing. The robot cannot be able to pass through vertical pipes.
	☒	☒	☑	☒	☒		
	☑	☒	☒	☑	High pressure liquid		
	☑	☒	☒	☑	☒		
	☑	☒	☒	☑	☒		
	☒	☒	☑	☑	☒		
	☑	☑	☒	☑	☒		
	☑	☒	☑	☒	☒		
	☒	☒	☒	☒	☒		
	☒	☒	☑	☒	Vacuum		
	☒	☒	☒	☑	Brush		
	☒	☒	☒	☒	High pressure liquid		
	☒	☒	☒	☒	Sweeping		
	☒	☒	☒	☑	Vacuum		
	☒	☒	☒	☑	Brush		
	☒	☒	☒	☒	☒		

Configuration	Inspection Application					Advantages	Disadvantages
	Flaws	Corrosion	Pain thickness	Visual inspection	Type of cleaning		
Caterpillar type	☒	☒	☒	☑	Cutting plate	Caterpillar wheels provide better grid to pass through the vertical and horizontal pipe.	The design of this robot is complicated.
	☒	☒	☒	☑	☒		
	☒	☒	☒	☑	☒		
Wall pressed type	☑	☒	☒	☒	Brush	These robots provide very good grip with pipe interior while climbing the vertical pipes, joints, elbows etc. It is used for pipe with varying diameter.	The in-pipe robots can only work for certain range of pipe diameter.
	☑	☒	☒	☑	☒		
	☑	☒	☒	☒	☒		
	☑	☑	☒	☑	☒		
	☒	☒	☒	☑	Vacuum cleaner		
	☒	☒	☒	☑	Cleaning portion		
	☑	☑	☑	☑	☒		
	☒	☒	☒	☒	Brush		
	☒	☒	☒	☒	Cleaning rod		
	☒	☒	☒	☒	Brush		
	☒	☒	☒	☒	Milling tool		
	☒	☒	☒	☒	Brush		
Walking type	☒	☒	☒	☒	☒	They can also travel in both horizontal as well as vertical pipes. The use of V-shaped legs makes it to pass through curves and bends easily.	The motion is much complicated. The leg has to move in synchronised manner for better locomotion.
	☒	☒	☒	☑	☒		
	☒	☒	☒	☒	High Pressure Jet		

Configuration	Ref. No.	Inspection Application					Advantages	Disadvantages
		Flaws	Corrosion	Pain thickness	Visual inspection	Type of cleaning		
Inch worm type	[36]	☒	☒	☒	☑	☒	They are very good in adaptability to change in pipe size.	These robots are suitable for pipes with very small diameters.
PIG type	[37]	☒	☑	☒	☑	Brush	Low cost and flexibility make it reliable device to use in pipelines.	Because of its less grip nature, PIG robots cannot use in vertical pipes.
	[38]	☒	☑	☒	☑	☒		
	[39]	☑	☒	☒	☑	☒		
	[40]	☒	☒	☒	☑	☒		
	[41]	☒	☒	☒	☑	☒		

Notes:

'☑' mark represents the previous work has been concentrated related to the particular task; '☒' mark represents the previous work has not been concentrated related to task.

2.3 Existing Attach Mechanism of In-Pipe Robot

The development of a moving mechanism is required in order to create a version of the robot that can fit in any pipeline condition. For the project's further development, there are several developments in robot movement mechanics that can be looked at and studied.

2.3.1 Triangular Structured Driving Mechanism In-Pipe Robot

This inspection robot, known as the DeWaLoP (Developing Water Loss Prevention) system, performs the standard pipe examination utilising a cable-tathered robot with an onboard video system. This mobile robot was created by Markus Vincze, Kai Zhou, and Luis A. Mateos. It has a differential wheel drive that enables it to quickly correct its position so that it moves through the middle of the pipe. Using a Dynamical Independent Suspension System (DISS), the maintenance unit of the structure can thus be compressed or expanded [13].

Figure 2-11 : Triangular Structured Driving Mechanism In-Pipe Robot

The In-Pipe Triangular Structured Driving Mechanism The robot system can operate without any vibration or involuntary movement caused by inertia and precisely grip the pipe joint by compressing its wheeled legs. The robot structure can form a rigid structure inside the pipe by expanding its wheels. The frame consists of six pairs of wheels and legs that are 120 degrees apart from one another. The legs served as the pipe's support system down the middle.

The idea behind this robot is to emulate a cylindrical robot that can traverse 3D in-pipe space but to modify the normal cylindrical robot into two cylindrical arms that are connected to the maintenance unit's central axis and spaced 180 degrees apart.

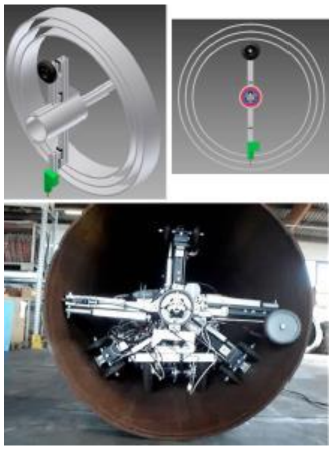

Figure 2-12 : Isometric View and Front View of Triangular Structured Driving Mechanism In-Pipe Robot

2.3.2 Flexible Wheel Mechanism Drive In-Pipe Robot

The Flexible Wheel Mechanism Drive In-Pipe Robot is an autonomous self-driven inline inspection robot that was created by et al. [14]. The flexible mechanism structure mimics how spider movement may adjust the uneven surface by being flexible to pass past the obstacle area or navigate at a corner or junction.

The body tube and the three flexible clutch mechanisms are the two fundamental components of the mechanism's structure. Three sets of flexible clutch mechanisms are positioned with a 120-degree angle interval on the robot's exterior, allowing the body to fit comfortably in pipelines with rounded cross sections.

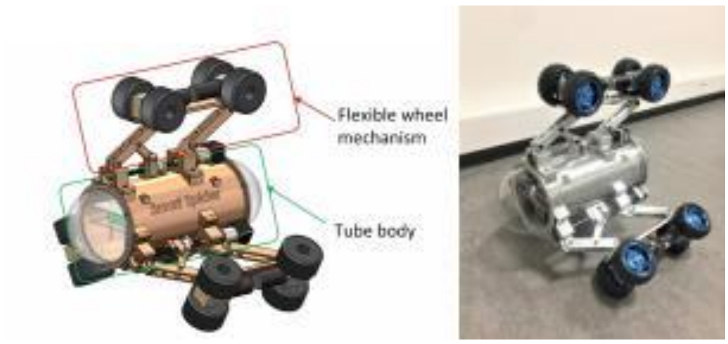

Figure 2-13 : The Mechanism Structure of the Flexible Wheel Mechanism Drive in Pipe Robot

By stretching and contracting, the drive mechanism is in charge of engaging the 4-bar linkage clutch, which is then followed by the wheels unit to accommodate various pipeline sizes. Stepper motors will be used to rotate the screw rod either clockwise or counterclockwise. As a result, the connector slider and U-shaped slider that cross each other on the screw rod can travel forward and backward, respectively. Following that, the 4-bar linkage's angle will change in accordance with the slider's position.

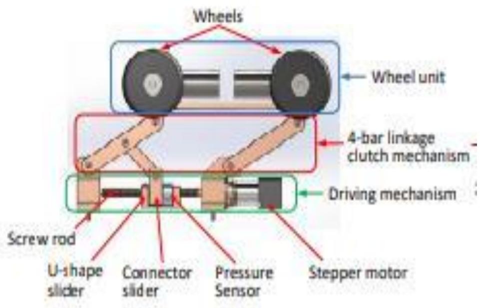

Figure 2-14 : The Horizontal Mechanism of the Flexible Wheel Mechanism Drive in Pipe Robot

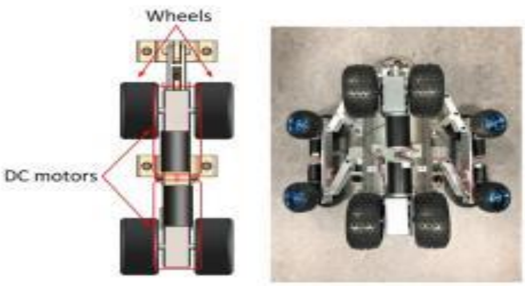

Figure 2-15 : The Top View of Flexible Wheel Mechanism of Flexible Wheel Mechanism Drive In-Pipe Robot

2.3.3 Magnetic Locomotion In-Pipe Robot

The Magnetic Locomotion In-Pipe Robot mechanism is presented by et al. [15] for an in-pipe robot that is designed to move from small diameter pipelines to larger bores. The aim is a ferrous pipeline with a diameter range of 50 to 1250 mm. At greater pipeline diameters, magnetic adhesion can perform adhesion without a wall-pressing mechanism. The pipes that can be inspected by a single robot are severely constrained by the wall pushing robot, as can be shown.

The 50mm internal diameter ferrous pipelines were intended to be entered by the magnetic pipe robot. The robot has soft rubber wheels made using soft-printed material and magnetic wheels. After the motors, electronics, and battery have been installed, the robot's main body is divided into two pieces and screwed together. The Arduino FTDI immediately mounts the wireless Bluetooth radio transceiver to the top of the chassis.

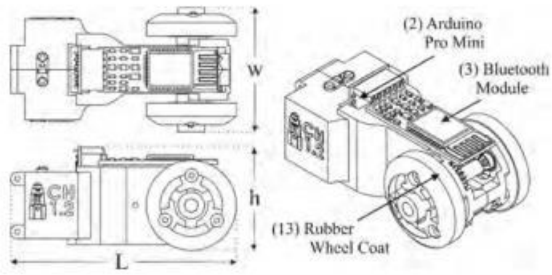

Figure 2-16 : Geometry of Magnetic Locomotion In-Pipe Robot

Fitting the robot inside a 50mm pipeline was a design restriction. Because of that restriction, the motors are positioned so that they face away from the driveshaft and the wheels. Parallel to one another, the motors are stacked. Each power a single gear train connected to the transmission by a bevel gear.

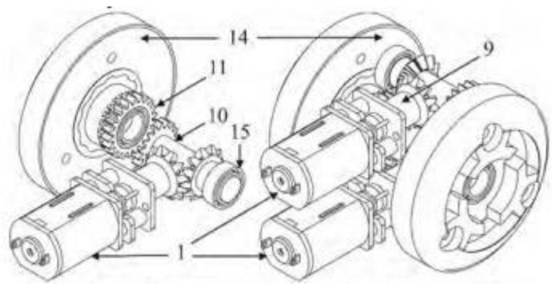

Figure 2-17 : Transmission System & Motor Layout of Magnetic Locomotion In-Pipe Robot, with Part No;.1: Motor, 9: Gear, 10: Driving Shaft, 11: Wheel Gear, 14: Magnetic Wheel

They are encased between two steel plates so that the magnets are not in direct touch with the interior surface of the pipe. It can safeguard the neodymium magnets while also rerouting the magnetic flux into the steel plates. Encasing the magnets makes them much safer from corrosion and shock impact, which can lead to degeneration and fracture.

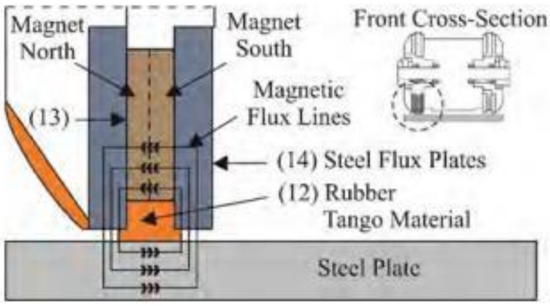

Figure 2-18 : Magnetic Locomotion In-Pipe Robot Cross-section Diagram

2.4 Existing Cornering Mechanism of In-Pipe Robot

To turn at the pipe junction, an in-pipe robot needs a cornering mechanism. On the robot's stability both before and after passing through the junction, the turning radius and angle are crucial factors.

2.4.1 Caterpillar Track Wheel-Based Robot

This Caterpillar Track Wheel-Based Robot's conceptual design is made up of a primary body, three foldable links, and three caterpillar wheel tracks [16]. The wheel tracks formed when the wall was pressed against them, increasing the force of their hold, and allowing them to climb walls without slipping. Furthermore, the robot uses a triaxial differential mechanism because the caterpillar tracks are positioned at a 120-degree angle to one another.

Figure 2-19 : Front View of Caterpillar Track Wheel-Based Robot