THE DESIGN AND DEVELOPMENT OF PIPELINE INSPECTION ROBOT

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THE DESIGN AND DEVELOPMENT OF PIPELINE INSPECTION ROBOT”

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in partial fulfillment of the requirements for the degree of
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2019

DECLARATION

I declare that this thesis entitled "THE DESIGN AND DEVELOPMENT OF PIPELINE INSPECTION ROBOT" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : --

Name : --

Date : --

APPROVAL

I hereby declare that I have checked this report entitled "THE DESIGN AND DEVELOPMENT OF PIPELINE INSPECTION ROBOT" and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Mechatronics Engineering with Honours

Signature : ....

Supervisor Name : ....

Date : ....

DEDICATIONS

To my beloved mother and father

ACKNOWLEDGEMENTS

Firstly, I would like to express my greatest gratitude to the people who have helped and supported me throughout my final year project. A very special thanks to my supervisor, Dr. Mohd Shahrieel bin Mohd Aras who have thoroughly giving me guidance, advices, and knowledge at every stage of my project progress throughout this whole semester. Without his guidance and persistent help, I would not be able to complete this project.

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ABSTRACT

Mobile robots have been developed and improved for decades in various designs with new specifications and features. Pipeline Inspection Robot (PIR) which is a type of mobile robot is operated autonomously with little to no human intervention, inspecting various field of the pipelines system and even cleaning the inner walls of the pipelines by using integrated programs. The development and application of mobile robot that is specifically used in monitoring the pipelines system are still not widely studied and applied although Malaysia is a nation that is vastly developing in the industrial fields. The proposed PIR can help in monitoring and inspecting pipes diameter ranging from 215mm to 280mm that are impossible to reach and hazardous to human life. In addition, the PIR is needed to make the inspecting operation easier and able to save work time. This project is focusing on the design and development of suitable PIR for pipeline system monitoring. The PIR is designed by using the *SOLIDWORKS* software and several simulations are conducted in the software such as the stress and strain analysis. The PIR is fabricated by using aluminium and uses the adaptive mechanism structure which allow the robot to adapt in pipe changing diameters. Moreover, the PIR is controlled by a microcontroller. Experiments are performed to verify the robot's performance such as the ability of the robot to adapt in the pipeline. The results shown that the PIR have an average speed of 0.0096m/s and can move accurately straight in the pipeline. Further modifications can be made to maximize the robot's capabilities.

ABSTRAK

Robot mudah alih telah dibangunkan dan ditambah baik selama beberapa dekad dalam pelbagai reka bentuk dengan spesifikasi dan ciri-ciri baru. Robot Pemeriksaan Paip (RPP) yang merupakan jenis robot mudah alih dikendalikan secara autonomi dengan sedikit intervensi manusia, memeriksa pelbagai jenis sistem paip dan juga membersihkan dinding dalaman saluran paip dengan menggunakan program bersepadu. Pengembangan dan penerapan robot mudah alih yang digunakan secara khusus dalam pemantauan sistem saluran paip masih belum diterapkan secara meluas walaupun Malaysia adalah sebuah negara yang sangat berkembang dalam bidang perindustrian. RPP yang dicadangkan boleh membantu dalam pemantauan dan pemeriksaan paip yang berukuran dari 215mm hingga 280mm yang mustahil dicapai dan berbahaya kepada manusia. Di samping itu, RPP diperlukan untuk membuat pemeriksaan paip lebih mudah dan dapat menjimatkan masa kerja. Projek ini memberi tumpuan kepada reka bentuk dan pembangunan RPP yang sesuai untuk pemantauan sistem saluran paip. RPP direka bentuk dengan menggunakan perisian *SOLIDWORKS* dan beberapa simulasi dijalankan dalam perisian tersebut seperti analisis stres dan ketegangan. RPP ini dibentuk dengan menggunakan aluminium dan ia menggunakan struktur mekanisme penyesuaian yang membolehkan robot menyesuaikan diri dengan perubahan diameter paip. Selain itu, RPP dikawal oleh mikropengawal. Eksperimen dilakukan untuk mengesahkan prestasi robot seperti keupayaan robot untuk menyesuaikan diri di dalam paip. Hasil eksperimen yang dijalankan didapati bahawa robot tersebut dapat bergerak dengan kelajuan 0.0096m/s dan dapat bergerak dengan tepat dan lurus di dalam paip yang disediakan. Pengubahsuaian lanjut boleh dibuat untuk memaksimumkan keupayaan robot.

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LIST OF SYMBOLS AND ABBREVIATIONS

PIR	-	Pipeline Inspection Robot
RPP	-	Robot Pemeriksaan Paip
mm	-	Milimeter
cm	-	Centimeter
m	-	Meter
kg	-	Kilogram
N	-	Newton
m/s	-	Meter per second
FYP	-	Final Year Project
V	-	Volt
A	-	Ampere
DC	-	Direct current
Kb	-	Kilobyte
Mhz	-	Megahertz
PWM	-	Pulse width modulation
USB	-	Universal serial bus
RAM	-	Random access memory
CCD	-	Charged-couple device

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Robotics are undoubtedly, one of the quickest engineering developments branches in this globalization era. Robots are developed and intended to abolish human intervention escalated and life-threatening job as well as to perform in unreachable environment [1]. The inspection of pipes is one of the tasks that is implemented in robots as it emerges to be one of the most engaging solutions [2].

The Pipelines Inspection Robot is a mobile robot that is equipped with a camera and specifically used to inspect various fields of the pipelines systems. The PIRs are used vastly in the supply of water, petrochemical and industries that working on fluid transportation [3]. On the other hand, the pipelines are the crucial equipment for transporting fuel oils and gas, delivering drinking water and transferring pollutants [4]. Piping networks can cause a lot of inconvenience such as corrosion, aging, cracks, and mechanical abrasion. Hence, the need of constant inspection, maintenance and repairs are massively needed [5]. The pipeline inspection robots are utilized to investigate internal disintegration, fractures and defects which are mainly due to many causes such as corrosion, degradation, and overheating [6]. With the decades of enormous developments in the robotics field, the pipeline robots have numerous designs such as the wheel typerobot, caterpillar type robot, wall-press robot, legged type robot, inchworm type robot and screw type robot [2].

In this project, a PIR is to be designed and developed by using the *SOLIDWORKS* software and the designs of the robot are specifically to apply in a straight pipeline system and it can adapt in a various pipelines diameter. The PIR will be programmed by a microcontroller which is the Arduino Mega2560. The performance of the PIR will be based on its ability to move in a various pipeline diameter and its ability to inspect the pipelines.

The aim of this project is to design and develop the PIR by using the *SOLIDWORKS* software, fabricate the robot and to analyze its performance. The goal of this project is to design and develop a PIR that is not too complex, low cost, able to adapt in various pipelines and multifunctional. However, the performance of other types of complex robot are detailed in this project.

1.2 Motivation

The pipelines are generally used for fluid transportation from place to place. The usage and application of pipelines across all over Malaysian industries are growing massively [7]. There are several industries that are very well known to the pipeline industries namely Lembaga Air Sarawak, Telekom Malaysia, Petronas and Indah Water. As an example, Petronas themselves is responsible to operate a huge number of 2500km of gas transmission pipeline in our country [8]. Nowadays, modern housing and town planning in Malaysia are mostly having centralized sewage system. With the utilization of the new sewage systems, all houses' pipelines will be connected to one station for each district. In addition, there will eventually be more future network of pipelines that will be constructed. These pipelines will require the constant need of maintenance and technology as the pipelines repair has become more vital [9].

There have been a series of accidents involving pipelines throughout the years. As claimed by Carl Weimer [10], the executive director of the Pipeline Safety, 135 excavation tragedy that involved pipelines have occurred in which the pipelines are transporting dangerous chemicals such as crude oil and petroleum over the last 10 years. This incident can be summarized that roughly one incident happens every month. A part from that, on the 31st of July 2014, gas explosion series had occurred in the the Cianjhen and Lingya districts of Kaohsiung, Taiwan. Earlier that evening, there were reports of gas spills and unfortunately, after the blasts, thirty-two people did not survive and a number of 321 others were wounded [11]. Recently this year, on the 1st of August, another series of natural gas pipeline explosion in Midland Country, Texas has occurred and five people were sent to hospital, leaving them with critical burn injuries. The cause of the explosions was unknown, the officials said [12].

These series of accidents could have been avoided if the pipelines were thoroughly inspected, maintained and repaired. Leaking of dangerous gas from the pipelines have cause casualties and other unfortunate events. By using and applying the pipelines inspection robot, the condition of the pipelines could be maintained and safety of human lives can be improved. This project is to design and develop a Pipeline Inspection Robot which can adapt in various pipe diameters in the pipelines and low cost that can be used to inspect the pipelines with a long-lasting life.

1.3 Problems Statement

The utilization of pipelines is very crucial in delivering unrefined and refined petroleum fuels such as oil, natural gas and biofuels and other different fluids including sewage, water, hot water or steam in a smaller reach. Next, pipelines are very useful for delivering water for drinking or water system over long gaps when it needs to move over slopes, or where trenches or channels are poor options because of evaporation, pollutions, or natural effect. These pipelines need to be inspected and maintained as the pipelines can suffer damages and corrosion if no repairs are to be done. However, the pipelines contain many dangerous substances to human and it is hard to investigate the pipelines by using only human power. Not only that, by using conventional ways of inspecting pipelines, the amount of work time increases.

Thus, robots are introduced and recently, many Pipeline Inspection Robot systems have been developed. The pipelines robot usually is equipped with camera and they are used to inspect the pipelines and to detect damages such as internal erosion, fractures and defects which are mainly due to many causes such as corrosion, degradation, and overheating. Therefore, by using the PIR, safety can be improved.

Furthermore, there are many Pipeline Inspection Robots that have been designed throughout the years. However, most of these robots are quite expensive to fabricate and develop because the robots are used in the pipelines and therefore the robots must be waterproof, long-lasting, high durability and other requirement factors. Thus, it is necessary to improve the performance of pipelines inspection robot performance in terms of the factor requirements.

Moreover, these robots have many types and their own way of mobility in the pipelines. Some of the pipelines robots that have been designed have adaptive mechanism in which they can adapt to the size of different diameter in the pipelines. However, these types of robots have different performance and efficiency throughout its journey in the pipelines. Therefore, it is necessary to analyse the performance of each type of robots based on its way of mobility.

1.4 Objectives

In this project, there are three objectives that are going to be achieved:

i) To design and analyze the Pipeline Inspection Robot by using *SOLIDWORKS* software.

ii) To develop and fabricate the Pipeline Inspection Robot.

iii) To analyse and investigate the performance of the Pipeline Inspection Robot.

1.5 The Scope and Limitations of the Project

The main scope of this project is to design and develop a Pipeline Inspection Robot with the integration of the adaptive mechanism on the robot. The designation of the PIR is carried out by using the *SOLIDWORKS* software and the stress and strain analysis and simulation is to carry out in the software as well. The size of the designed robot is to fit a straight pipeline with the diameter of 215-280mm. The robot has three sets of linkage that is connected between the wheels and the body. Each set of linkage consist of 2 sets of wheels and each linkage has a DC motor connected to the 2 sets of wheels. The programming is written and load into a microcontroller board (Arduino Mega2560) that is attached inside the robot's body.

1.6 Summary

As the conclusion of this chapter, it explains the importance of Pipeline Inspection Robot usage in the piping system and industries. The design and development of the Pipeline Inspection Robots must be carried out thoroughly in terms of durability, performance, materials and the design itself. The aim of this project is to design and develop PIR with the utilization of the adaptive mechanism and to analyse its performance in the pipeline systems.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, literature review is discussed from journals or conference papers that are affiliated to this study in order to accomplish the objectives of this research. There are many papers have been studied in order to design and develop the Pipeline Inspection Robot. Seven categories of the Pipeline Inspection Robot designs are reviewed in this chapter. Furthermore, the microcontroller for the designed robots are also discussed in this chapter.

2.2 Types of Robot Designs

There are many types of robots, especially in the pipeline category, many robot designs have been developed. These type of pipeline robots have specific designs and can be classified as the Wheel Type Robot, Helical/Screw Type Robot, Inchworm Type Robot, Legged Type Robots, Caterpillar Wall Press Type Robot, Wheeled Wall Press Type Robot and Wall Press Wheeled Screw Type Robot.

2.2.1 Wheel Type Robots

The wheel type robots have simple and plain structure as well as improve velocity maneuver with small car-like-structure [3]. The Wheel Type Robot resemblance the ordinary mobile robot and a few researchers have presented on usage of in-pipes mobile mechanism with even compact than 1inch inner diameter [2]. As proposed by M. F. Yusoff *et al*, the wheel type robots, in order to get the desired type of mobility, the wheels are connected directly to the DC motor [13]. The robot can move similarly to a car like forward, backward, and by using servo motor the robot is able to turn right and left. Besides that, this robot is also equipped with motorized brushes on the bottom of the robot for cleaning purposes [13].

Figure 2.1: The Wheel Type Robot by M.F. Yusoff *et al*. [13]

The design of the robot that is presented by M. R. A. M. Zin et al is mostly based on the ability of the designed robot to fix in the pipelines with the diameter of 80 mm and the robot's capability to lift its own weight in the pipelines [14]. The robot uses magnet disc for its wheel rims which is the Neodymium (NdeB), a class of one of the rare magnets of the Earth that is used widely for contemporary gear like motors and hard disk drives. This type of magnet is chosen to be the accomplishable method for application of magnet wheels because of its high size strength proportion [14].

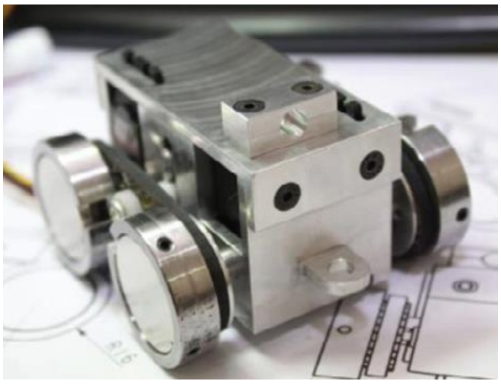


Figure 2.2: The Wheel Type Robot by M. R. A. M. Zin *et al.* [14]

Furthermore, K. Suzumori, T. Miyagawa, M. Kimura, and Y. Hasegawa have designed a complex Pipeline Inspection Robot in micro size for 1inch inner pipes with the applications of the wheel type robot. The prototype provides fine mobility and is equipped with functionality appropriate for practical use. The robot has the external diameter of 23mm, length of 110mm and weighs about 16g and attached on the robot front is a CCD camera with 410 000-pixel colour that allocates sufficient resolution to detect 25µm fractures in the inner walls of the pipeline systems. The interesting part of this wheel type robot is that, it has double arm-like-system with the freedom of six degrees for the usage of controlling and to retrieve little objects.

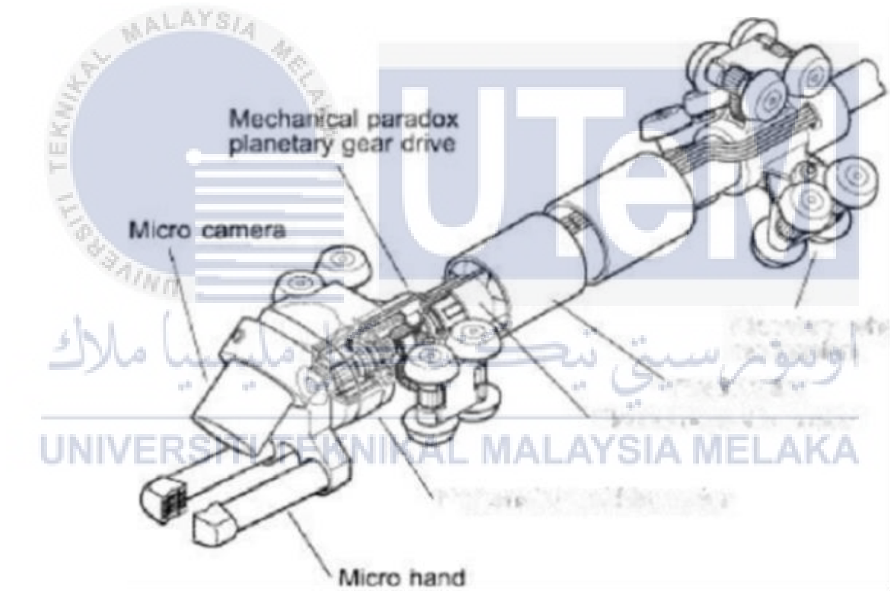


Figure 2.3: The Wheel Type Robot by K. Suzumori *et al.*

2.2.2 Helical/Screw Type Robots

The screw type robots have two main parts which are the stator and the rotor [3]. The rotor is composed of three inclined wheels with an individual angle. The rotor is attached towards the motor and the rotor transforms the revolution of the motor into the robot translation. Moving on to the stator, it comprises of three straight wheels that act as the stability contribution to the screw drive type robots and restrain the robot from force of reaction because of the rotation of the rotor. Motivated by the movement of a bacteria named Spirochetes, M. Kurata *et al*. has developed a prototyped that is operated by motors and pulleys [15]. The Spirochetes features a helical body that enables it to rotate about the axis of its body to produce propulsive power. Hence, this type of motion should be efficient due to its entire body generating the propulsive force [15].

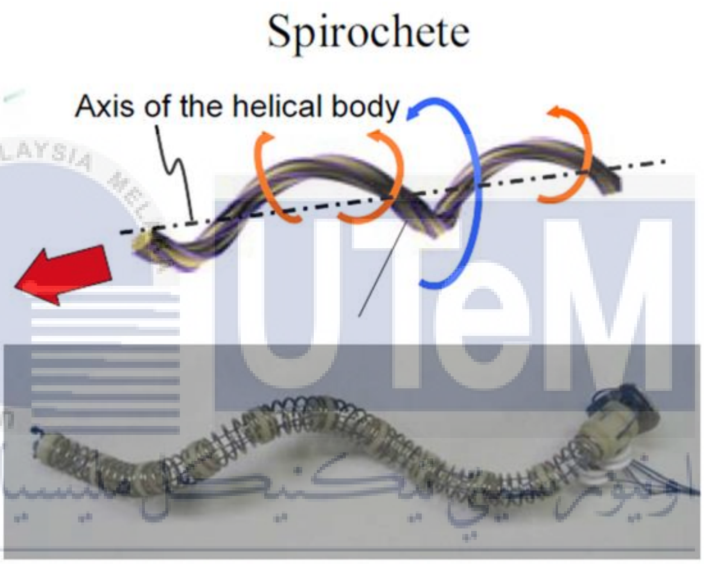


Figure 2.4: The Spirochete and the Prototype by M. Kurata *et al.* [15]

Next, there is also another prototype of screw type robot that is proposed by Osuka *et al*. named SPRING [16]. The SPRING is a piping inspection robot that can move freely in the pipelines. The name is given as it reassembles the structure of an everyday spring. However, this prototype has revealed two main problems that have been obtained through repeated experiments. Firstly, the SPRING halts after decelerate rapidly when proceeding to a valve in the pipelines section which is due to the fore fins of the prototype being obstructed by the valve wall because SPRING was not sufficiently distorted. Secondly, the SPRING was immovable when pass into the elbow in the pipe because of its tires slipping. This problem is due to the tires not reaching the wall of the pipes because the angle between its body exterior and the inner wall is bigger when moving in the elbow [16]. These problems are later solved by redesigning its body length, wheel form, stiffness and wheel alignment.

Figure 2.5: The Screw Type Robot Prototype SPRING by Osuka *et al.* [16]

2.2.3 Inchworm Type Robot

Besides the robots that are using wheels to move, there are also types of robot that do not use wheels for locomotion. The inchworm type robot by Megumi Ikeuchi *et al.* [17] which have the likeness of inchworm movement in the pipelines with the support of one flexible module and two clamping. This prototype can move in a 16mm pipe. Furthermore, this robot is designed and generated by applying the movement of a real earthworm and it has several units which comprises of a spring rolled aluminium sheet, two flanges, and artificial muscles. To achieve its desired movement, the artificial muscles enlarges in the radial direction and shrinks in the axial direction when air is supplied to the chamber. Next, the artificial muscle extends in the axial direction when air is discharged from the chamber. Hence, the locomotion system similar to an earthworm can be acquired by repeating the contracting and expanding movement [17]. The structure of the robot is shown in the Figure 2.6 below.

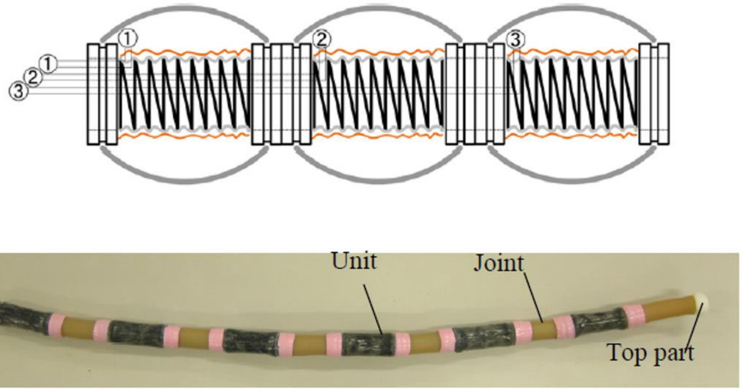


Figure 2.6: The Structure of the Inchworm Type Robot by Megumi Ikeuchi *et al.* [17]

A part from that, K. H. Yoon and Y.W. Parle [18] have proposed a Pipeline Inspection Robot that is operated by using compressed air. This robot is developed and designed to meet a few requirements. Firstly, the power source of this robot can withstand massive temperature and pressure. Next, the prototype has the ability to conquer the vertical pipelines without causing any skidding. In addition, the robot can fit into the pipelines with the diameter of 100mm and able to expand to a diameter of 300mm. Hence, a pneumatic system is chosen as the power source to fulfil the first requirement because of potential existence of remaining high temperature and high pressure. Moreover, for the achievement of the second requirement, an inchworm mechanism is favoured due to its vertical-climbing ability. Lastly, a two-bar linkage mechanism is adapted due to its easy extension and shrinking ability in radial direction. The concept proposed is like folding and unfolding an umbrella and the whole structure size can be modified following to the change in length of link [18].

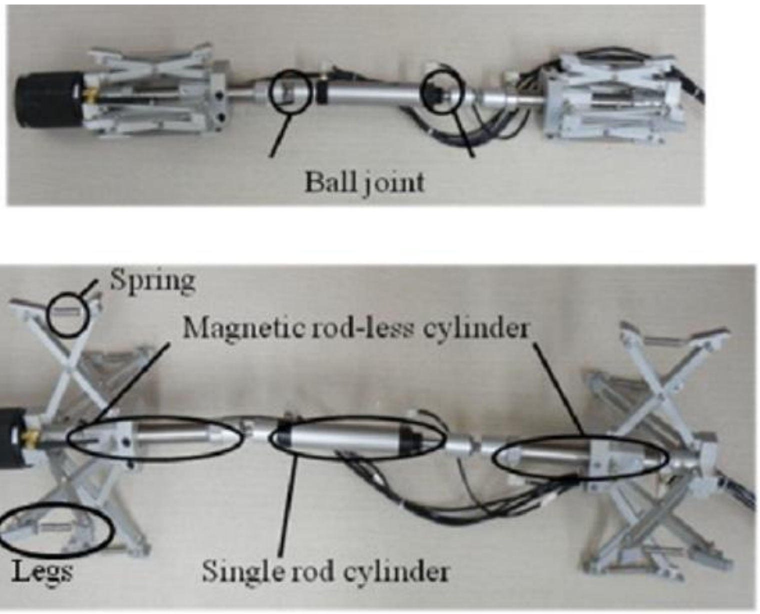


Figure 2.7: The Inchworm Robot by K. H. Yoon *et al.* [18]

2.2.4 Legged Type Robot

The Legged Type Robot uses leg to move instead of using wheels. Firstly, the leg type robots that has been suggested by Robin Bradbeer *et al.* [19] and Zagler *et al.* [20] is made possible to climb in any spatial type of the pipelines such as horizontal and vertical concerning with any sort of pipeline junctions namely the ‘T’, ‘Y’, and ‘L’ joints [3] Robin Bradbeer *et al.*’s robot is utilized for the underwater inspection of the internal pipelines system. The robot is consisting of an underwater camera on a servo motor powered mount, four pneumatically controlled legs and it is 1m in length with the diameter of 300mm. The robot is equipped with propellers that is actuated by electric placed either side of the body at the rear for propulsion through the water. The robot can be flipped over and hence, the legs can be either at the top or the bottom of the pipelines. The buoyancy will provide the force for the legs to grip the surface [19].

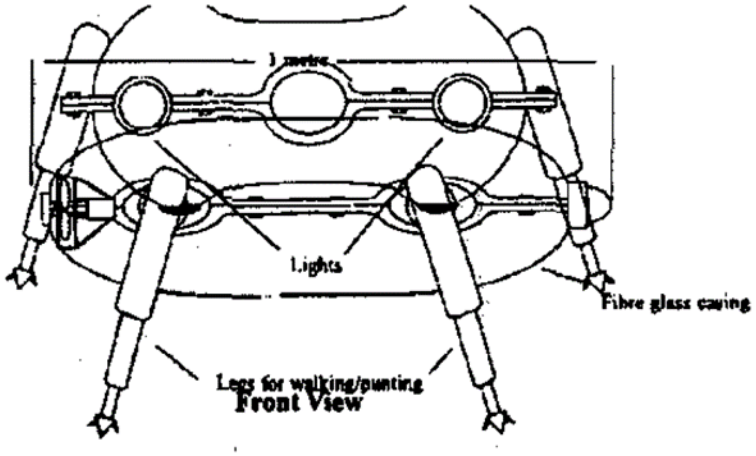


Figure 2.8: The Legged Type Robot by Robin Bradbeer *et al.* (1997) [19]

Next, a different concept of a legged type robot that has been developed and designed by Zagler *et al.* at the Technical University of Munich [20]. The robot has been given the name 'MORITZ' and it can climb through pipes of different inclination. Rossman *et al.* [21] built a robot that is capable of climbing into vertical and horizontal pipes. The robot is also developed so that it can move through pipe junctions and this robot can manages curved pipes with a 60 to 70mm diameter. To achieve its movement capabilities, the robot is equipped with eight legs and each leg is equipped with two driven joints which can achieve torques up to 78Nm. Next, to move the robot, the robot spreads its four legs to the wall of the pipe to produce friction forces. Thus, its weight of 20kg and an additional load can be carried while the other four legs swing to the next stance. The figure below shows T. Rossman *et al.* legged type robot [21].

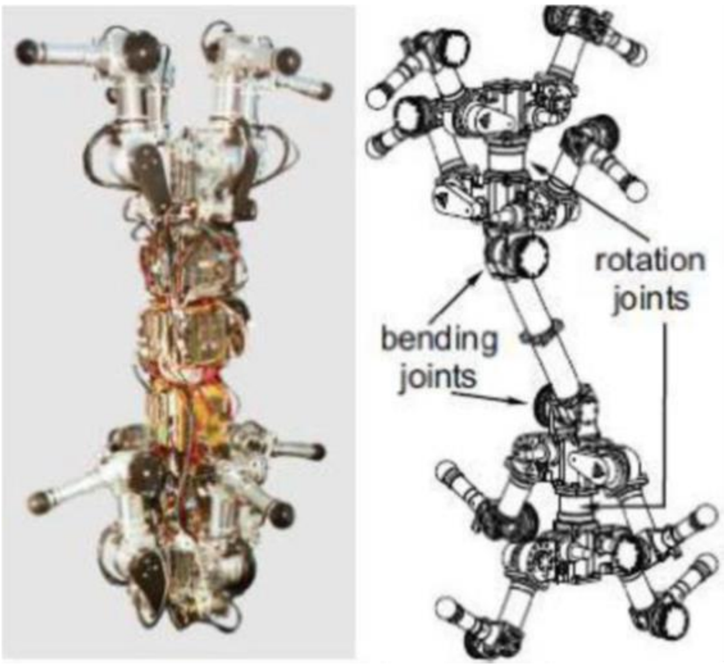


Figure 2.9: The Legged Type Robot by Rossman *et al.* [21]

2.2.5 Caterpillar Wall Pressed Type Robot

Generally, the Caterpillar Type Robots use belted-bound-wheels which are linked to the actuators. The caterpillar wheels deliver spare friction to the robot and makes it possible to achieve locomotion on intermittent surfaces in the pipelines. Moreover, the Wall Pressed Caterpillar Type Robots are designed and developed to move and mount on vertical as well as inclined pipelines with uneven interiors with its caterpillar tracks holding to the inner wall of the pipes [3][19] Caterpillar track tyres supply the robot with the ability to move forward and backward with great grip force and with the combination of the wall press feature and the caterpillar track wheels, it permits the robot to adjust in diverse inner pipes diameters. Generally, this type of robot comprises of three main parts which are the main body, the caterpillar wheels and the elastic linkage mechanism. The Figure 2.10 expresses the general structure of the caterpillar wall-pressed type robot [6].

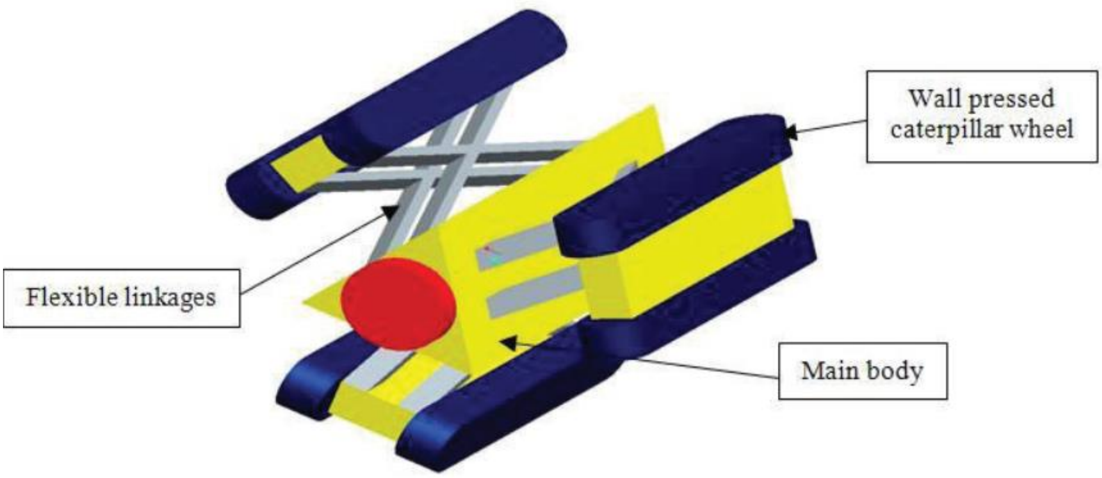


Figure 2.10: The General Arrangement of the Caterpillar Wall Pressed Type Robot [6]

The robot that have been proposed by Jong-Hoon Kim *et al*. the FAMPER [22], is designed and developed to inspect 150mm pipelines and equipped with four caterpillar track wheels that carry the expandable link mechanism. Its elasticity has granted the robot to move in disfigured pipe systems and can conquer hindrance. Next, the caterpillar track wheels are equipped to its rectangular central body can contract from 157mm to 127mm. Flexible links and spring behave as a suspension system to produce supportable performance in an unknown pipeline condition. The caterpillar wheels are supplied with flexible shaft to give aid for the caterpillar body. The shaft enables the FAMPER to decrease up to half of its length. Furthermore, each of the caterpillar track wheels are supervise unconventionally to ensure that the robot can steer in pipeline junctions by modifying their speeds. A part from that, the FAMPER is proposed and developed with peculiar self-adjustability mechanism and can conquer obstacle. The Figure 2.11 below shows the structure of the FAMPER [22].

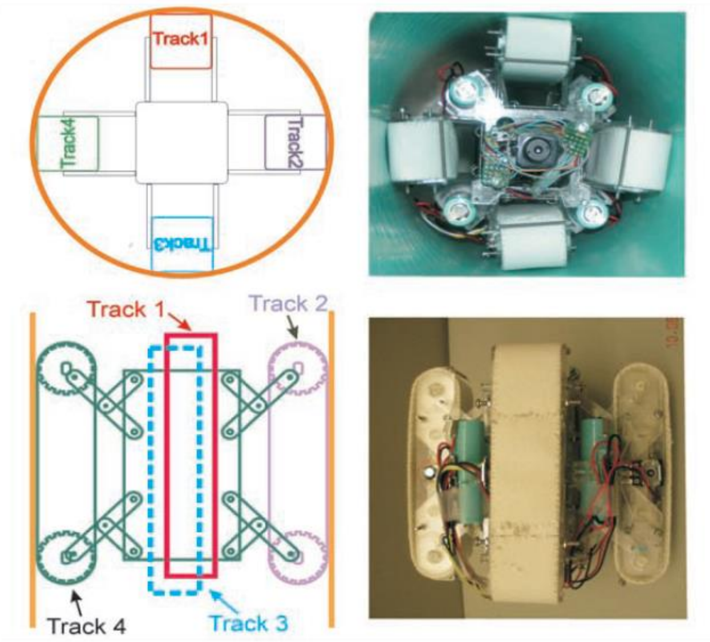


Figure 2.11: The Caterpillar Wall Press Type Robot FAMPER by Jong-Hoon Kim *et al.* [22]

Furthermore, there is also the caterpillar wall press type robot that has been designed and developed by Atsushi Kakogawa et al. [23] that uses similar design as the FAMPER. But instead of using four caterpillar track wheels, this robot only uses three independent caterpillar track wheels driving modules that is equipped with four bar linkage mechanism attached to the wheels to its body. The wheels are equipped with a pair of spur gears to lift the linkage and the entire body in the pipelines. The robot uses spring tension as a passive support which enables the robot to keep contact to the pipe walls and can adapt in pipeline diameter of 136mm to 236mm and it has the maximum speed of 0.23 m/s. To change the adaptive diameter, the robot crawler module is connected to a central base unit through passive pantograph mechanisms. Each pantograph is radially assembled with an interval of 120° and a slider moves along the horizontal shaft that is passively pushed by a 0.3 N/mm spring [23].

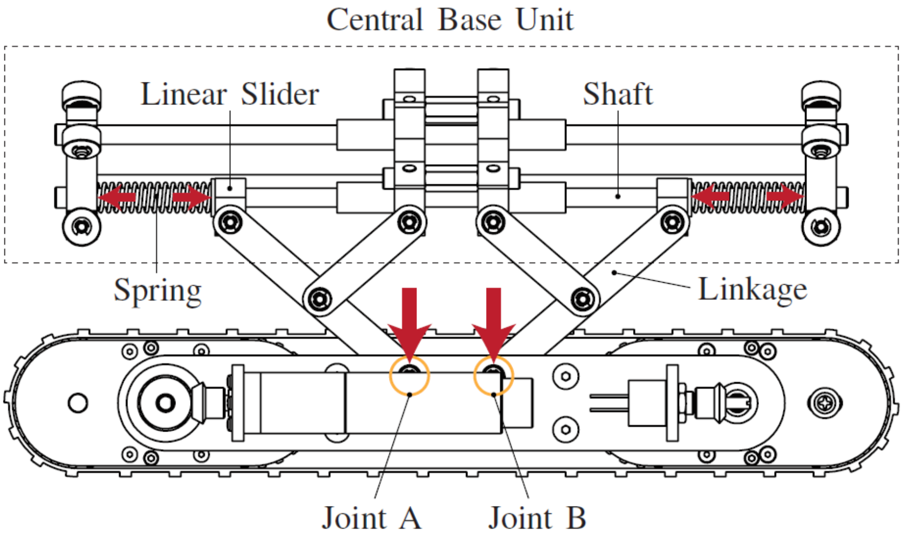


Figure 2.12: A Pantograph Mechanism Used to Change the Diameter of the Robot [23]

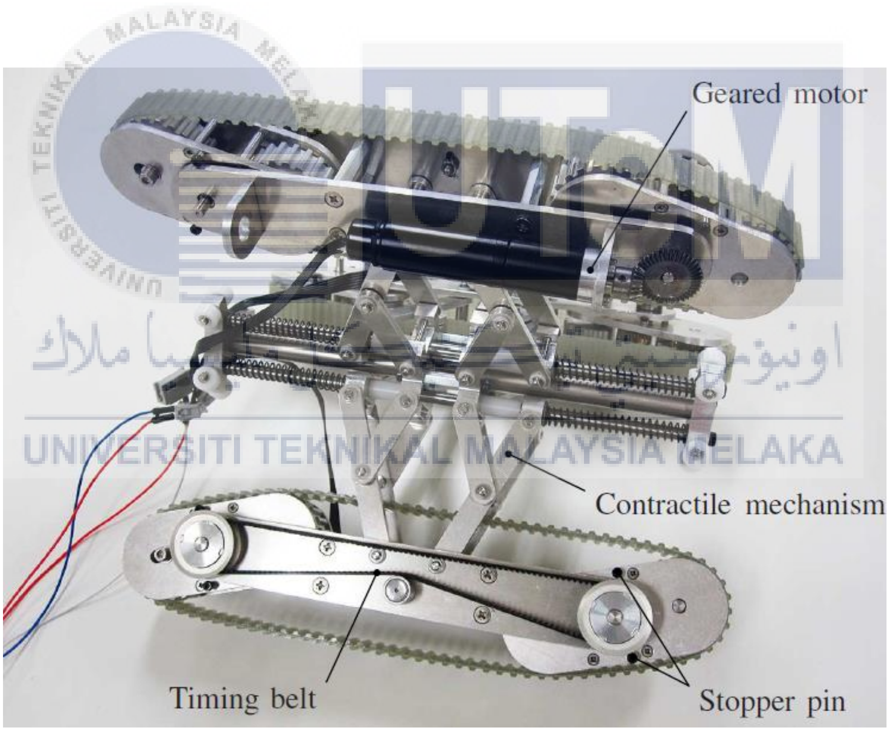


Figure 2.13: The Caterpillar Wall Press Robot by Atsushi Kakogawa *et al.* [23]

2.2.6 Wheeled Wall Press Type Robot

The wheel type robot drive system delivers great maneuver capability particularly for traversing in the pipelines. Merging these specifications in a Wall Press Type Robot escalate the execution of a usual Legged Wall Press Type Robot. Furthermore, this sort of robot has its own importance as far as simple structure for specific design necessities. A part from that, wheels are way effective to deliver rapid movement speed contrasted to the caterpillar track wheels [6]. The Figure 2.14 below portrays the general composition of the Wall Press Wheeled Type Robot that comprises of the main body, wheels and flexible linkage structure:

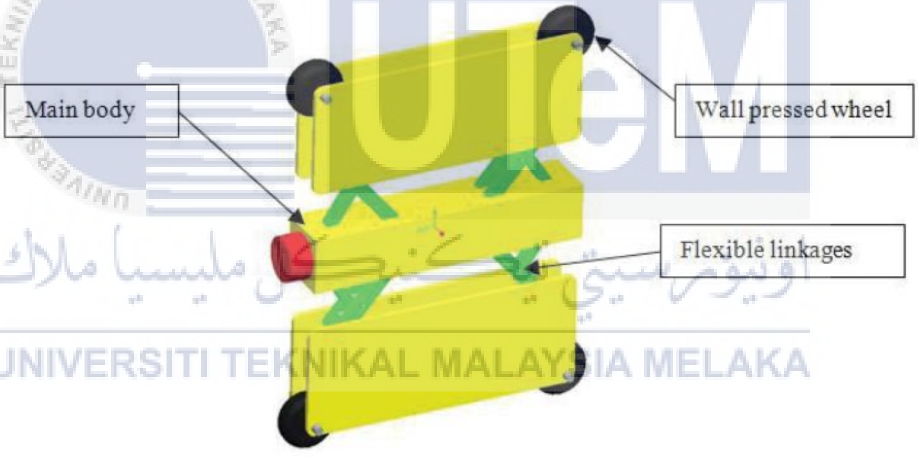


Figure 2.14: The General Composition of the Wall Press Wheeled Type Robot [6]

Y.S. Kwon *et al.* [24] have designed and developed a unique wheeled wall press type robot with two-wheel chains. Like any other Wall Press Type Robot, this robot uses the folding mechanism to modify its size to changes of the pipeline diameters. This robot is designed and developed to inspect pipelines with the diameter ranging from 80mm to 100mm. The robot wheel chains are positioned 180° apart assisted with parallel folding structure to the main body frame. Hence, more spaces are accessible to hold additional cameras on the other two sides of the body. Furthermore, this robot has a special operation feature called the detecting mode. The detecting mode is the robot's screw motion ability which enables the robot to move nearer and record vivid pipe walls image by utilizing the side camera. This ability is achieved by situating the wheels in an inverse way. The turning capability can be attained by steering the same angle of wheel chains in the same direction of turning. These two movements allow wheel type robots an ascendancy contrasted to the Caterpillar Type Robots. Unlike any other wall press type robots, this movement framework requires less portability control since it just need a similar speed to turn the robot in respective direction. If there is no steering angle, the robot can navigate in a linear motion and this is called the driving mode operation. Y.S. Kwon *et al.* has demonstrated in their experiment that with only one module, this new application can overwhelm the motion singularity difficulty [24]. The Figure 2.15 below shows the proposed Wheeled Wall Press Type Robot:

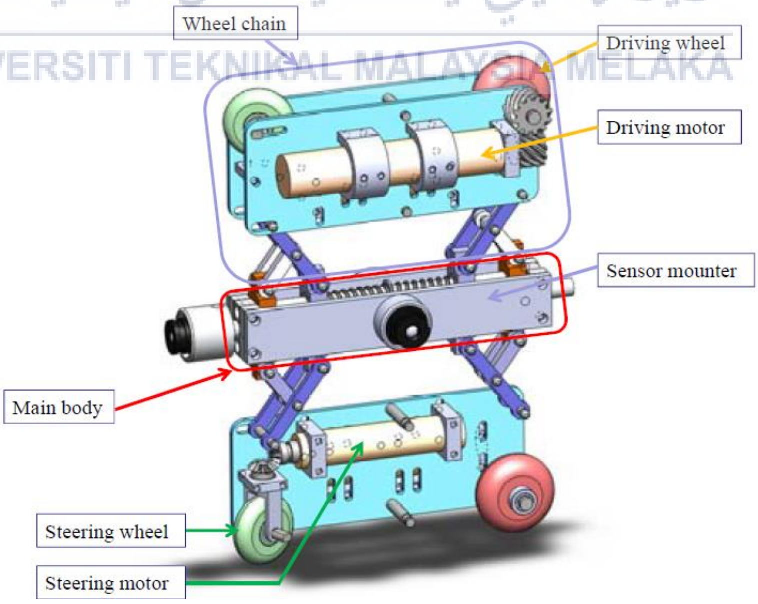


Figure 2.15: The Structure of the Wheeled Wall Pressed Type Robot by Y.S. Kwon. *et al.* [24]

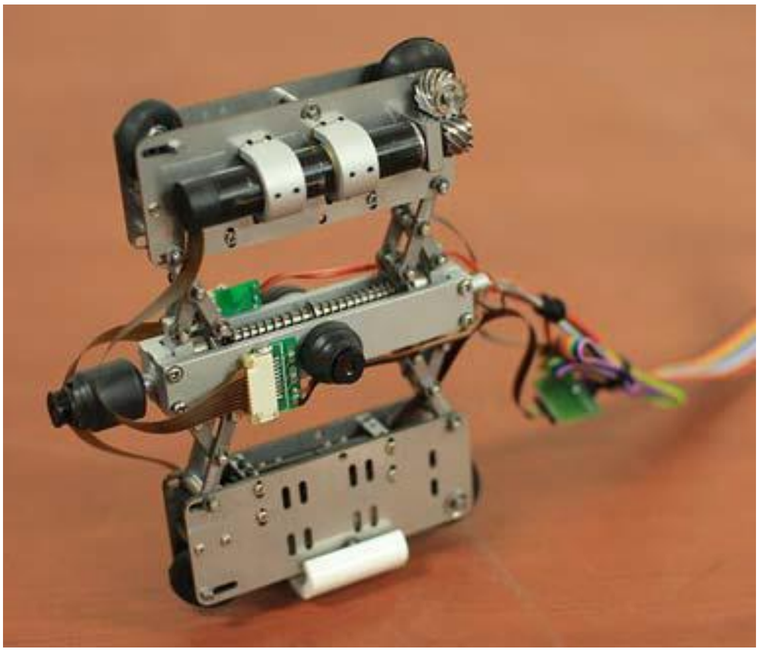


Figure 2.16: The Structure of the Wheeled Wall Pressed Type Robot by Y.S. Kwon. *et al.* [24]

Moving on, Y. Qu *et al*. [25] has designed and developed The Smart-Spider Autonomous Self-Driven Pipeline Robot which is the wheeled wall press type robot. This robot, regarding to the spider itself, the mechanism structure consists two parts which are the main body and the flexible mechanism. On the other hand, the electronic system manages the motion control, leg automatic adaption, data collection and storage. The main mechanism structure of the robot is comprised of two parts which are the tube body and the three flexible clutch mechanisms. These two parts are made up of aluminium alloy. The rack of the electronic system which consist of the battery and two layers of electronic PCBs and components are fixed inside the tube body. On the exterior part of the tube body, the three sets of flexible wheels mechanisms are integrated with 120° interval angle which enable the Smart-Spider to adapt well in the pipelines. Each of these flexible wheel’s mechanism consists of three units which are the driving mechanism, the linkage clutch mechanism and the wheel units. Every wheel unit is composed of two sets of wheels and every wheel set consist of two wheels which is driven by a DC motor. Furthermore, two transparent acrylic domes are fabricated at the front and the rear sides of the tube body respectively. The Smart-Spider can adjust it exterior diameter from 450mm to 575mm and it has the length of 426mm with the exterior diameter of 300mm. In order to be more compact and flexible, a screw rod is used to replace the common spring axe and an improved 4-bar structure is design for the linkage clutch mechanism. The driving mechanism is responsible for actuating the 4-bar linkage clutch mechanisms to extend or contract, followed the wheel units to adjust to different pipeline diameters. The screw rod is driven by a stepper motor to revolve clockwise or anticlockwise. Therefore, the U-shape slider and the connector slider crossing on the screw rod can move forward and backward respectively. Then, the angle in the 4-bar linkage clutch transforms according to the position of the sliders, which determines the exterior diameter of the Smart-Spider [25].

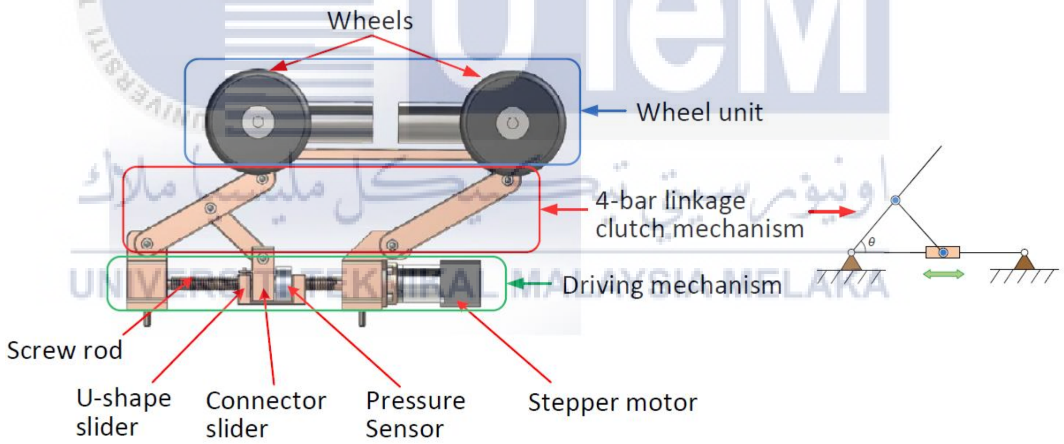


Figure 2.17: The Horizontal View of the Flexible Mechanism of the Smart-Spider [25]

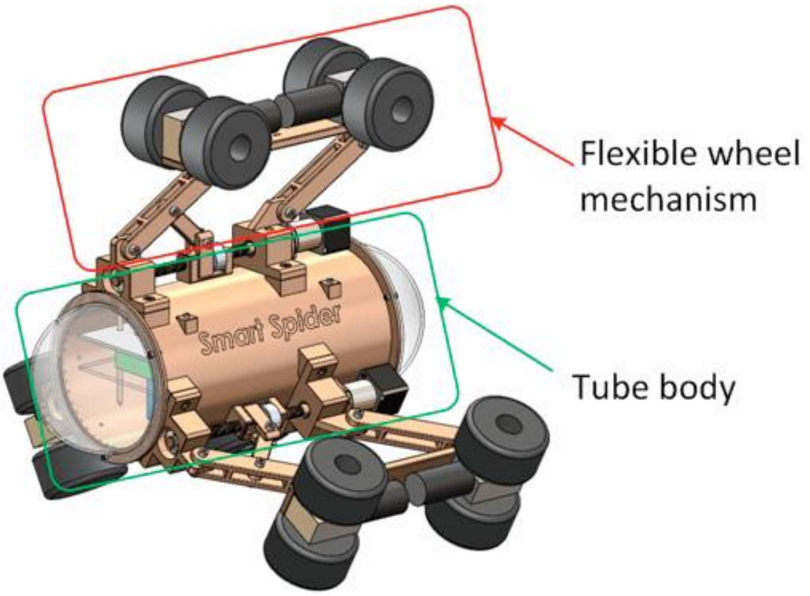


Figure 2.18: The Wheeled Wall Press Type Robot by Y. Qu *et al.* (The Smart Spider) [25]

2.2.7 Wall Pressing Wheeled Screw Type

Three types of movement systems are integrated in the Wheeled Wall Pressing Screw Type Robot. Generally, a rotator and a stator is needed in screw type motion robot to produce the desired type of locomotion [3]. The wheel specification in the robot supplies less friction force between the typical screw type and the inner pipeline walls. The best feature about the Wheeled Wall Pressing Screw Type Robot is that it needs at least one actuator to move [6]. The Figure 2.19 below portrays the general arrangement of the Wall Pressing Wheeled Screw Type Robot:

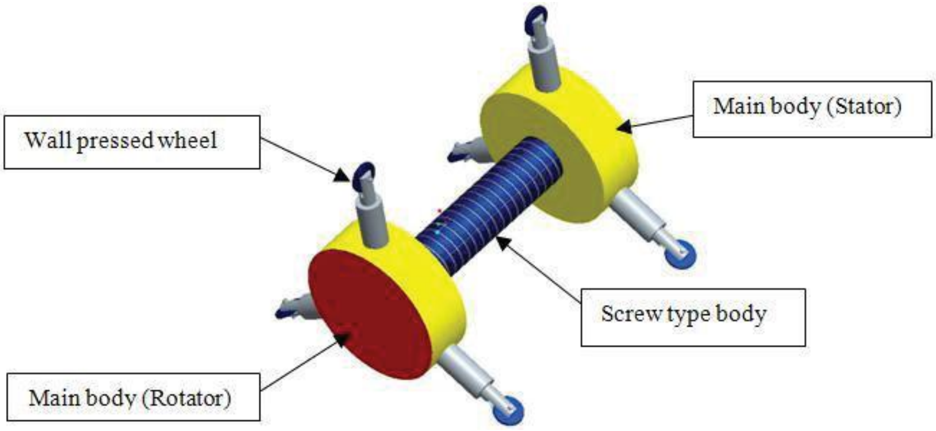


Figure 2.19: The General Arrangement of the Wall Pressing Wheeled Screw Type Robot [6]

Y. H. Zhang *et al.* [26] have proposed and developed an elastic Squirm Type Robot which is one of the Wheeled Wall Pressing Screw Type Robot that integrates three mobility system by utilizing at least a motor. The robot has an ice cream cone shape that gives an advantage in turning its position. The squirm type robot by Y.H. Zhang *et al.* comprises of two parts, which are on the left, the ice cream scoop shape and the right body which is also the cone or right. The squirm type robot can perform a screw driving mechanism by using its flexible helical axle and the gear nut that is located in the body of the ice cream scoop. The specialty of this robot is that it can be operated in online condition where the pressure caused by flowing fluid is used to drive the robot. On the other hand, this robot is equipped with magnetic wheel devices that can adapt in the pipeline diameter changes by controlling its leg or guide rod. Support from the magnetic wheels helps the robot to lift the whole robot body and maintain onto the iron wall. A part from that, there is the brake that have been installed in the leg which provides electromagnetic force to the permanent magnet wheel. For the robot to move in the pipe, while the helical axle pushed the right body, the left body has to be fixed on the wall of the pipelines. Reversing the motor direction can drive the left body to the right and to steer the robot, a guide head is utilized. The guide head is installed in the right body and consists of controlled rods that determine the turning angle and these controlled rods are interconnected to the left body. For the robot to move in an L-type junction, the guide head will escort the structure of the junction to turn. The guide head rotation axis is parallel to the flexible helical axle when the flexible helical axle bends. In addition. The controlled rods are pulled by the left body to angle itself in 45° to move in the T-branches while the same procedures to turn in junctions are applied [26].

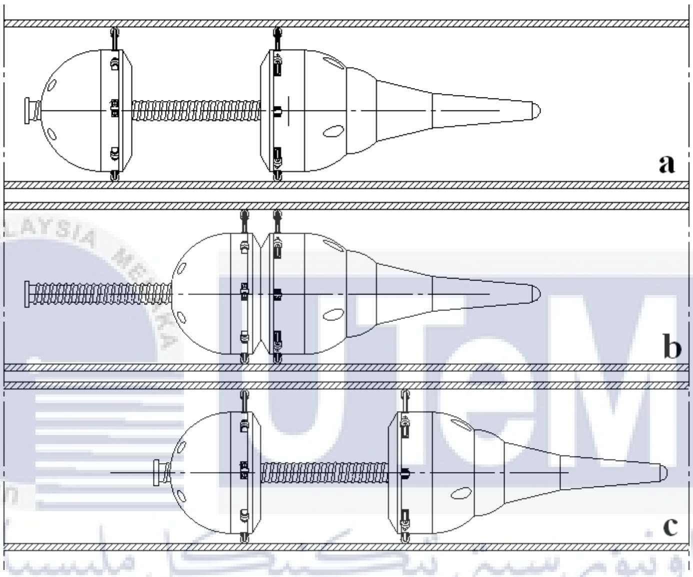


Figure 2.20: The Process of Squirm Walk [26]

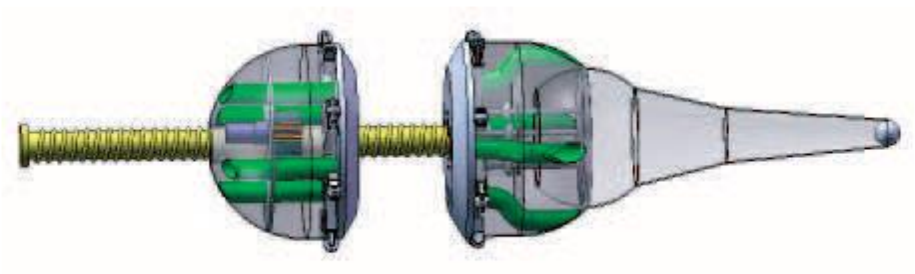


Figure 2.21: The Wall Press Wheeled Screw Type Robot by Y.H. Zhang *et al.* [26]

Table 2.1: General Comparison of the Types of Pipeline Inspection Robot [2]

Types of Robot	**Advantages**	**Disadvantages**
Wheel	• Simple mechanism • High propulsion efficiency so the robot can move quick • Energy efficient • Easy to design and fabricate • Not so costly	• Cannot adapt to the size of the pipelines • High propensity of skidding • The wheels may stuck if there is a obstacle or hole • Hard to retrieve the robot if lost connection in the pipelines
Helical/Screw	• Flexible movement • Since it does not drag its body, the inner pipelines wall would not damage • Does not obstruct the stream of liquid inside the pipe	• Very complex structure • May get stuck in the pipelines if the mechanism does not work appropriately • Takes more time to design and fabricate • Very costly to fabricate the robot parts
Inchworm	• Can operate both on plane and liquid	• Very complex structure • Great drag force may harm the internal pipelines wall

		• Takes more time to design and fabricate
Legged	• Less tendency of slipping inside the pipelines • Has the ability to climb pipes of various inclinations	• Very complex structure and mechanism • Leg might stuck in the pipelines if there is a hole or obstacle • Take more time to design and fabricate • Very costly to fabricate the robot parts
Caterpillar Wall Pressed	• Adaptable to changes of various pipes diameter • Have the ability to conquer uneven pipe surfaces • Large contact area with the inner pipeline walls • Suitable for long range pipe inspection • Great grip force to the inner pipeline walls	• High friction force • Very complex wheels structure and mechanism • Takes more time to design and fabricate • Very costly to fabricate the robot parts
Wheeled Wall Pressed	• Simple mechanism • Minimal actuator • Adaptable to changes of various pipes diameter • Suitable for long range pipe inspection • Can act as a payload	• Less efficient on uneven pipeline walls • Takes time to design • Costly

	• Great grip force to the inner pipeline walls	
Wheeled Wall Pressing Screw	• Adaptable to changes of various pipes diameter • Great grip force to the inner pipeline walls	• Very complex structure and mechanism • Takes more time to design and fabricate • Very costly to fabricate the robot parts

2.3 Microcontroller

A microcontroller is a compact integrated circuit designed to govern a specific operation in an embedded system. A typical microcontroller includes a processor, program memory (RAM) and input/output (I/O) peripherals on a single chip. Microcontrollers have been widely used and embedded in the devices, machinery and system such as automobiles, robot system, telephones, security system and automatically controlled devices. Hence, in this part of the literature review, there are four types of microcontrollers that are discussed which are the Arduino Uno, and Microbox 2000/2000C, Arduino Nano and Arduino Mega2560.

2.3.1 Arduino Uno

According to the journal of M.S.M Aras, M.F. Basar, S.S. Abdullah, F.A. Azis and F. A. Ali [27], it presented the Arduino Uno as shown in the Figure 2.22 which is used as a microcontroller of the system. The Arduino Uno is a microcontroller board based on the ATmega 328 by Atmel. It has 14 digital input/output pins and 6 analog inputs. It features

32Kb flash memory, 2Kb SRAM and 16 MHz of clock frequency. It also consists of a USB interface and a power jack for 9V to 12V AC to DC adapter connection. Its operating voltage is 5V. An ICSP header of the Arduino is used to upload programming language from an Integrated Development Environment (IDE). In this journal, the Arduino Uno is used as a microcontroller of the system and interfaced with sensing unit (IMU sensor). The Arduino Uno is one of the famous microcontrollers that are used in mobile robots especially in university projects because of its cheap price and reliability.

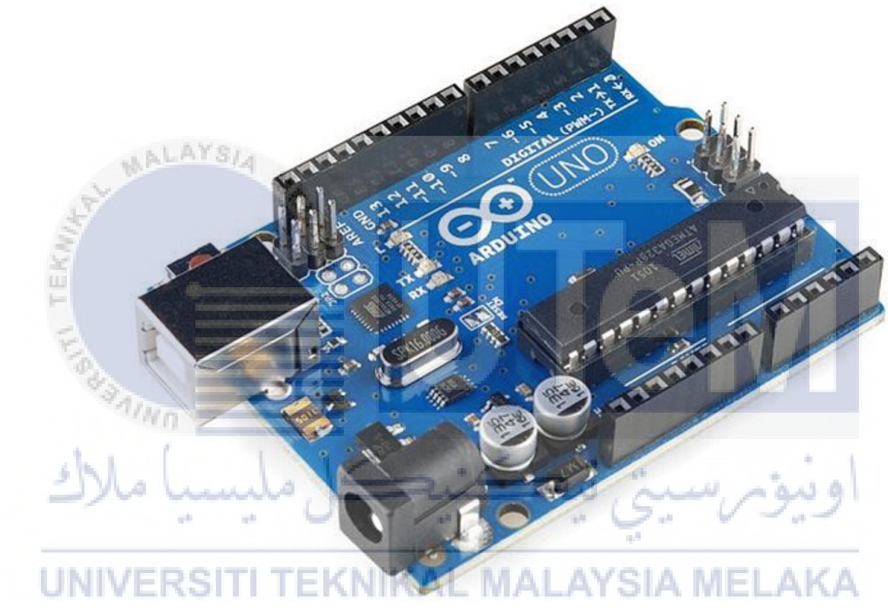


Figure 2.22: The Arduino Uno

2.3.2 Microbox 2000/2000C

Microbox 2000/2000C is a high performance and low power consumption PC as shown in Figure 2.4. According to Mohd Shahrieel Mohd Aras, Fadilah Abdul Azis, Shahrum Shah Abdullah, Lee Dai Cong, Lim Wee Teck, Fara Ashikin Alic and Muhammad Nur Othman [28], Microbox 2000/2000C is used to interface between the ROV hardware and MATLAB software. It is also called as XPC target machine and can act as a microcontroller for hardware interfacing. It is an excellent device to integrate with

MATLAB/Simulink and other control modules such as real time modelling, control system simulation, prototyping and hardware loop testing without any manual code or debugging. Therefore, the time and costs are saved because the control system design and testing can be easily done.

Figure 2.23: The Microbox 2000/2000C

2.3.3 Arduino Nano

According to C. R. Rocha *et al*. [29], the Arduino Uno is chosen as the microcontroller for the Mission Monitoring/Control System (MMCS) to supervise the underwater vehicle. Arduino Nano board is a small and complete board based on the ATmega328. It has 14 digital input/output pins (6 provide PWM output) and 8 analog inputs. It features 32KB flash memory, 2KB SRAM and 16 MHz of clock frequency. It consists of a mini USB interface but no DC power jack. Its operating voltage is 5V. The mini USB header of the board is used to upload programming language from an IDE and supply power.

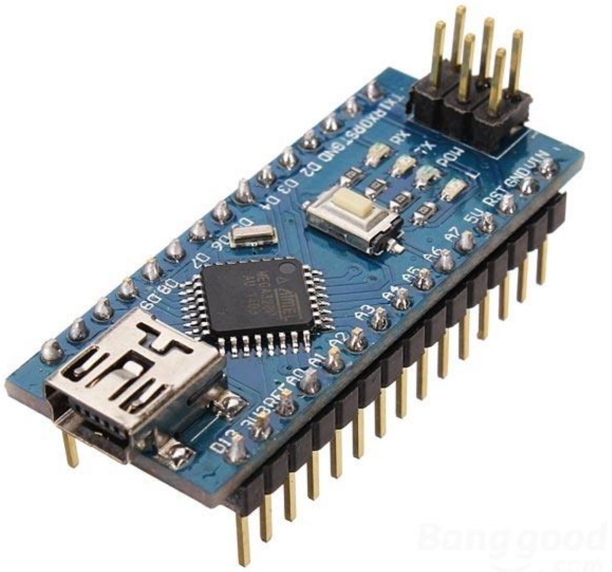


Figure 2.24: The Arduino Nano

2.3.4 Arduino Mega2560

According to J. Busquets, J. V. Busquets, A. Perles, R. Mercado, R. Saez, J. J. Serrano, F. Albentosa and J. Gilabert [30], the Arduino Mega2560 is chosen as a main controller unit (MCU) of the sensors as shown in Figure 2.2. Arduino Mega is an 8 bits 100 pins microcontroller board based on the ATmega 2560 by Atmel. It has 8Kb SRAM, 4Kb EEPROM, 256Kb flash memory and 16 MHz clock frequency. It has 54 digital input/output pins and 15 of them can be used as PWM outputs, 16 analogue inputs of 10 bits resolution, 4 UARTs (hardware serial port), I2C and SPI. This platform is the most reliable and high performance 8 bits microcontroller board available today by Arduino. All the components, devices or programming can easily interface with Arduino microcontroller boards because most of the header and connector are compatible. It can be used to connect to a computer with a USB cable or powered with an adapter or battery.

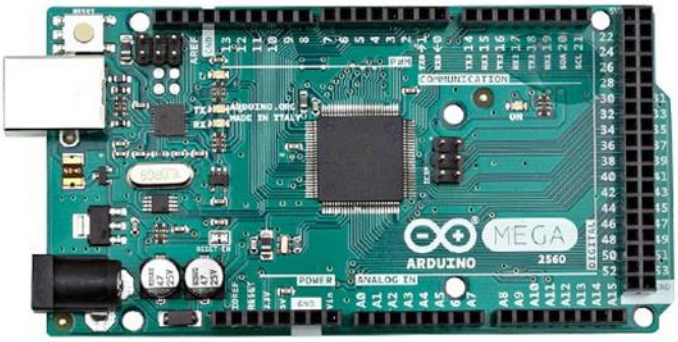


Figure 2.25: The Arduino Mega2560

Table 2.2:The Comparison of the Microcontrollers

Micro-controller	**Specifications**	**Advantages**
Arduino Uno [28]	• 14 digital input/output pins • 6 analog inputs • 32Kb flash memory • 2Kb SRAM • 16 MHz clock frequency • 5V operating voltage	• Simple programming language • Able to read the analog value from analog sensor
Arduino Mega2560[31]	• 54 digital input/output pins • 16 analogue inputs • 256Kb flash memory • 8Kb SRAM • 16 MHz clock frequency	• Simple programming language • Able to read the analog value from analog sensor • More input/output pins available

	• 5V operating voltage	• High flash memory
Arduino Nano [30]	• 14 digital input/output pins • 8 analog inputs • 32KB flash memory • 2KB SRAM • 16 MHz of clock frequency • 5V operating voltage	• Simple programming language • Able to read the analog value from analog sensor • Small in size • Low cost
Microbox 2000/2000C [29]	• 4 encoder channel • 16 digital I/O channels • 4 D/A channels • 8 A/D channels	• Low power consumption • Able integrate with MATLAB/Simulink and other control modules • Able to run without any manual code or debugging. • the time and costs can be saved • Simple to design control system and testing

2.4 Summary

The basic knowledge for designing and constructing the Pipeline Inspection Robot have been analysed and discussed. The different designs and types of Pipelines Inspection Robot are compared.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, the methodology of the project is discussed in order to design, develop and analyse the Pipeline Inspection Robot. The overall process flowchart of the project, electrical and mechanical parts descriptions, simulation analysis and experimental test methods are discussed. This chapter gives a bigger picture on how the project is progressing so that it can be finished successful.

3.2 Project Development Flow Chart

The flowchart in Figure 3.1 shows the summary process of this research. The flowchart also acts as the guideline for the completion of the project.

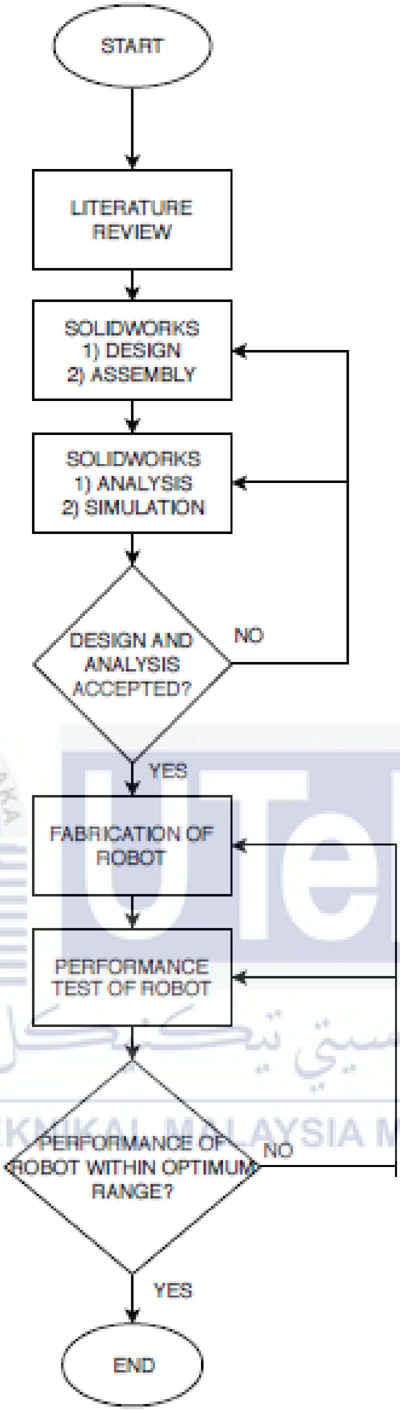


Figure 3.1: The Overall Process Flow of the Methodology

3.3 The Block Diagram of the Designed Robot

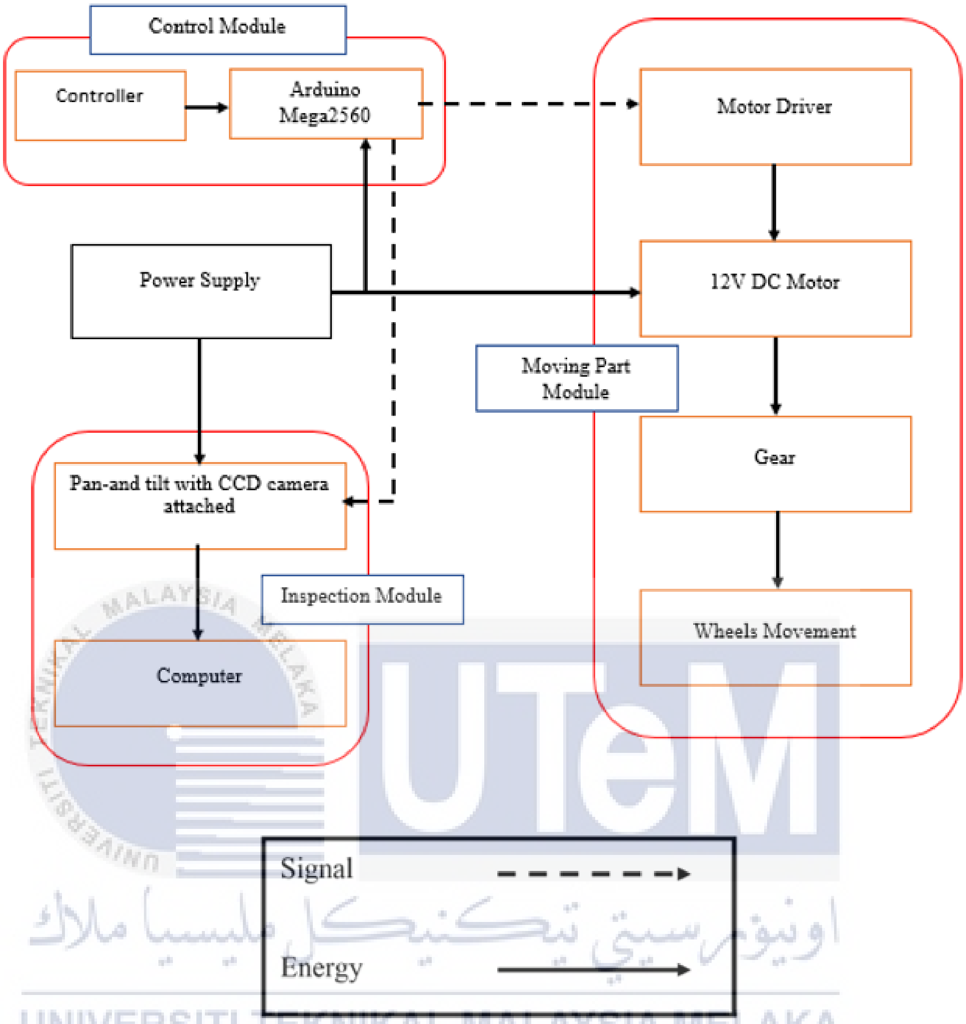


Figure 3.2: The Block Diagram of the Designed Robot

The whole system has been constructed as shown in the Figure 3.2 above. The control module consists of the controller that is wired connected with the Arduino Mega2560. The inspection module consists of the pan-and-tilt CCD camera that is attached with servo motor and the computer that is used to get real-time image or video recording for pipe inspection. Next, the moving part module consists of the motor driver, 12V DC motor, gear and the wheels movement. The whole module is powered by a power supply that is connected externally from the robot.

3.4 Mechanical Parts Description

3.4.1 The Pipeline Inspection Robot Body Tube

The body tube of the Pipeline Inspection Robot act as the main body of the whole robot. The body tube that is shown in the Figure 3.3 is designed in the SOLIDWORKS software. The body tube has 3 spaces to mount the 4-bar linkage that connected to the wheels. The front and the rear of the body tube is connected with transparent acrylic plastic to protect the inside of the body tube. The inside of the body tube is where the electrical components are stored.

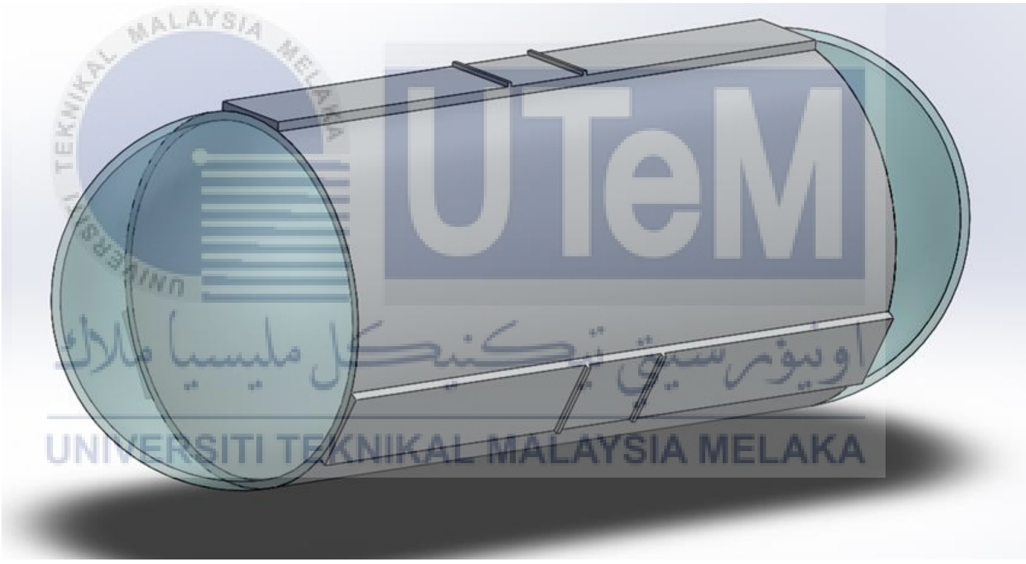


Figure 3.3: The Pipeline Inspection Robot Body Tube

3.4.2 The 4-Bar Linkage Arm of the Pipeline Inspection Robot

The 4-bar linkage that act as the arm of the robot is connected between the body tube and the wheels. This linkage also acts as the adaptive mechanism for the Pipeline Inspection Robot. The spring that is connected on externally on the shaft acts as a passive support. The spring enable the whole arm to contract and expand base on the size of the pipe diameter.

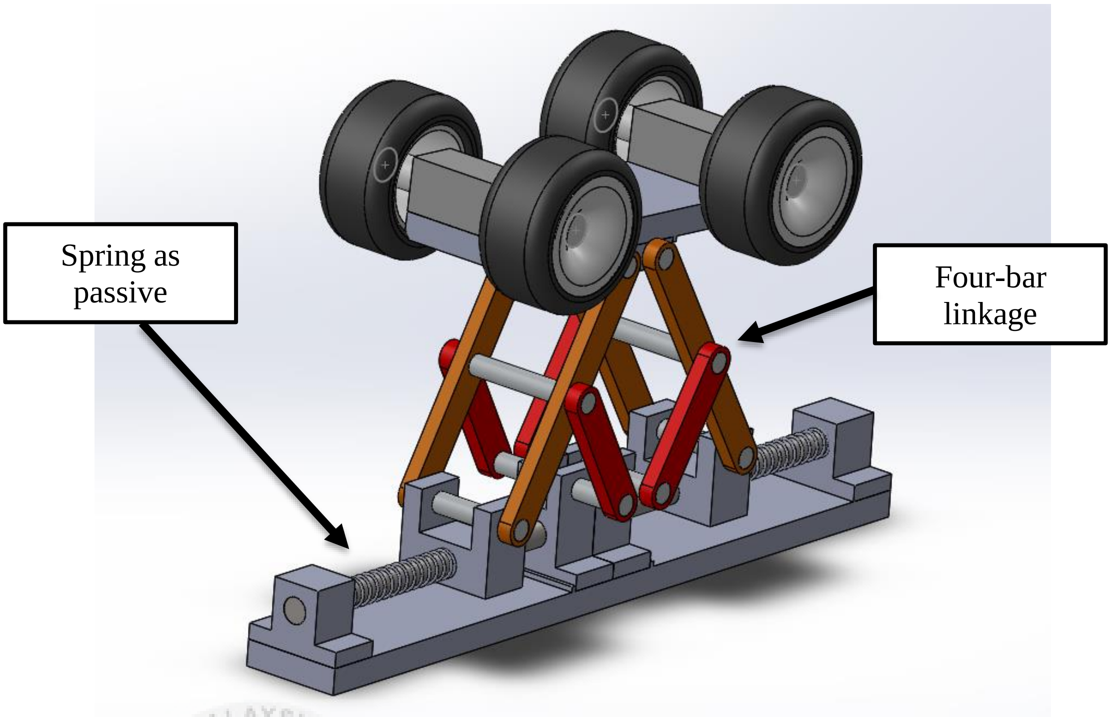


Figure 3.4: The Adaptive Mechanism of the Pipeline Inspection Robot

3.5 Electrical Parts Description

3.5.1 Power Supply

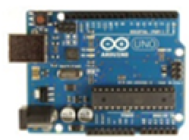
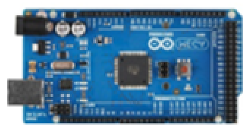
Power supply used is the 12V 7.2Ah lead-acid battery which is used to power up the Pipeline Inspection Robot. In term of power capacity, the lead-acid battery performs better than the lithium polymer or lithium ion.

Figure 3.5: 12V 7.2Ah Lead-Acid Battery

3.5.2 Microcontroller

Microcontrollers are utilized to manage the Input and Output (I/O) according to the executed program code. Arduino is an open-source computing platform that created microcontroller board for building digital devices and interactive objects to control the physical devices. Arduino microcontroller board is famous for its precision in executing its I/O pin that is very suitable for controlling the Pipeline Inspection Robot. In choosing the suitable microcontroller for this project, there are several features that need to consider as tabulated on the Table 3.1. The Table 3.1 tabulated the similarities and differences between the Arduino Uno and Arduino Mega2560. From the Table 3.1, the main differences between these two microcontrollers are the number of the input/output pins and flash memory. The better the specifications of the microcontroller, the better the performance for the Pipeline Inspection Robot. Hence, the chosen microcontroller that will be used in this project is the Arduino Mega2560 which is more efficient for the development of the Pipeline Inspection Robot.

Table 3.1: Comparison between the Microcontrollers

Type of microcontroller / Aspects	Arduino UNO 	Arduino Mega2560 
Operating voltage	5V	5V
Digital I/O pins	14	54
Analog input pins	6	16
Flash memory	32 KB	256 KB
SRAM	2KB	2KB
Clock speed	16 MHz	16 MHz

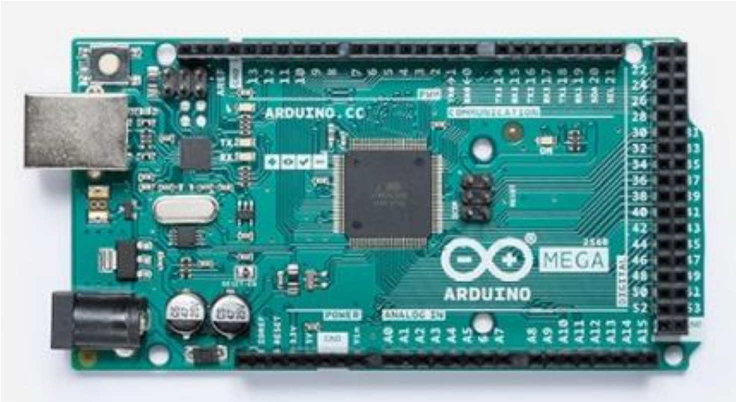


Figure 3.6: The Arduino Mega2560

3.5.3 DC Motor

This DC motor provides high torque and speed for the Pipeline Inspection Robot where it is suitable for pipe inspection. The DC motor that will be used for this project is the Mini 4WD Atomic Tuned Motor Pro. The DC motor speed is controlled by using Pulse Width Modulation (PWM). The datasheet which consists the specifications of the DC motor is shown in the table 3.2 below:

Figure 3.7: The Mini 4WD Atomic Tuned Motor Pro

Table 3.2: Parameters of the Mini 4WD Atomic Tuned Motor Pro

Parameters	**Values**
Manufacturer	Tamiya 15351
Rated voltage	2.4 ~ 3.0V
Proper Load	0.98mN*m (10g*cm)
Shaft Diameter	2.0mm
Dimension	25.1mm x 20.1mm
Weight	18.7g
Rated load speed	16200 RPM

3.5.4 Motor Driver

The motor driver Arduino L293N Motor Driver Shield will be used in this project to control the DC Geared Motor. Since the microcontroller used in this project is the Arduino Mega2560, it requires an extra component to control the DC motor because the microcontroller cannot control the DC motor directly. Arduino Mega2560 only provide recommended voltage supply from 7V up to 12V and the current rating from Arduino Mega2560 is insufficient to operate the DC motor. The Arduino L293N Motor Driver Shield specifications and diagram are shown in the table 3.3 and Figure 3.8 respectively.

Table 3.3: The Specifications and Features of the Arduino L293N Motor Driver Shield

Specifications and Features
• Logic control, 5V from Arduino main board
• Polarity protection for External motor power input
• 2 interfaces for 5V Servo connected to the Arduinos high-resolution dedicated timer

• 4-channel driver, can drive 4 DC motors or 2 stepper motors or 2 Servo
• Up to 4 bi-directional DC motors with individual 8-bit speed selection
• Motor Driven Voltage：6.5 to 12VDC (VIN Power Supply), 5.0 to 36VDC (External Power Source)
• Up to 6A current each channel
• 4 H-Bridges: per bridge provides 0.6A (1.2A peak current) with thermal protection, can run motors on 4.5V to 36V DC
• Support PWM speed control and advance speed control

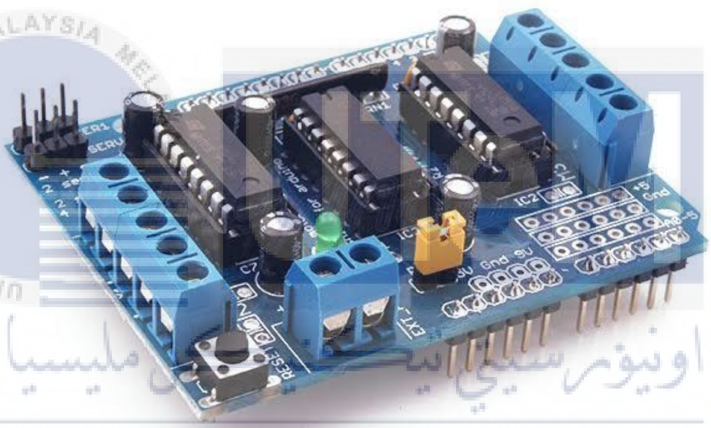


Figure 3.8: The Motor Driver

3.5.5 Joystick

A joystick is an input device that is used to manually control the Pipeline Inspection Robot. In this project, an analog joystick as shown in Figure 3.9 will be used to control the movement of the Pipeline Inspection Robot. This joystick will be implemented in the Pipeline Inspection Robot to control the movement of the robot in forwarding and backward only.

Figure 3.9: The Joystick

3.5.6 Servo Motor and Pan-and-Tilt

The servo motor act as the support and pan-and-tilt for the CCD camera. The servo motor allows the camera to move in a 180° vertically and horizontally for the effectiveness of inspection in the pipeline. The Figure 3.10 below shows the pan-and-tilt servo motor.

Figure 3.10: The Servo Motor and Pan-and-Tilt

3.5.7 CCD Camera

The CCD camera will be used and installed inside the body tube of the Pipeline Inspection Robot. This camera acts as the tool for the robot to do inspection inside the pipelines. The Figure 3.11 shows the 700TVL 2.3mm 1/3 CCD 150 Degree Wide Angle FPV Camera that will be used inside the Pipeline and the Table 3.4 shows the specifications of the CCD Camera.

Figure 3.11: The CCD Camera

Table 3.4: The Specifications of the 700TVL 2.3mm 1/3 CCD 150 Degree Wide Angle FPV Camera

Parameters/Specifications	**Values**
Lens Angle	150 Degree
Sensor	1/3" Sony SUPER HAD II CCD
Resolution	700TVL (b / w), 700TVL (colour)
Minimum Illumination	0.01Lux
Privacy Areas	8 areas
Working Voltage	5V - 36V
Working Current	70mA
Dimension	19x19mm

3.6 The Design and Assembly of the Pipeline Inspection Robot

The design and assembly of the Pipeline Inspection Robot is done mainly in a computer by using the SOLIDWORKS software after thoroughly reviewing and researching the suitable design for the robot through past researches. Thus, after reviewing the designs and types of the robot, there are two final designs that have been chosen and a few aspects that need to be considered as shown in the table 3.2 below. Table 3.2 listed out the key differences and similarity between these two designs for further understanding. From the table 3.2, the main difference between these two robots is the type of the robot. One is the caterpillar wall press type robot by Atsushi Kakogawa et al. which uses the caterpillar track wheels for mobility and the other is the wheeled wall press type robot by Y. Qu *et al.* which shows simpler structure and mechanism than the caterpillar type. The goals of the design are to develop a Pipeline Inspection Robot that are able to adapt to various pipe diameters, less complex structure and mechanism, low cost and able to inspect the pipelines. Based on the table 3.2, although the caterpillar wall press type robot has better traction on uneven surfaces, the design structure and mechanism of the robot is very complex. Hence, complex structure and mechanism will take more time to design in the SOLIDWORKS software. A part from that, this complex structure and mechanism will take much more time to be fabricated and the cost of the fabrication will be more expensive. Therefore, the final decision of the robot design used in this project is the wheeled wall press type robot by Y. Qu *et al.* which has better approach to the goals of the designed robot. However, the wheeled wall press type robot uses active linkage support which is the stepper motor to connect the wheels to the tube body that acts as the adaptive mechanism, while the caterpillar wall press type robot uses spring as a passive support. Hence, instead of using the active support in the wheeled wall press type robot, this project decided to use the spring as a passive support for the adaptive mechanism to reduce the complexity of the design, save time and reduce the cost of the fabricated robot.

Table 3.5: Comparison between the Designs of the Robot

Types Of Robot / Aspects	**The Caterpillar Wall Pressed [24]** 	**The Wheeled Wall Press [26]** 
Ability to adapt to pipe changes	Very well adapt in various pipe diameters and in uneven pipe surfaces	Very well adapt in various pipe diameters and fairly perform in uneven pipe surfaces
Complexity of structure and mechanism	Very complex wheel structure and mechanism	Simple wheel structure and mechanism
Type of linkage support	Uses spring as passive linkage support between the caterpillar wheels and the body	Uses stepper motor as an active linkage support between the wheels and the tube body

3.7 The Analysis and Simulation in the SOLIDWORKS Software

After completing the design and assembly of the robot, the analysis on the materials use on the robot parts and simulation is done using the SOLIDWORKS software. In order to have the robot to withstand the condition in the pipelines, stainless steel has been chosen as the material of the robot parts because of several reasons. Firstly, the stainless steel is well known for its resistance towards corrosion and oxidation. This characteristic is very important to the Pipeline Inspection Robot as the pipelines contain many types of liquid.

Furthermore, the stainless steel has good forming and welding properties which will make the fabrication of the robot possible. In addition, the stainless steel has excellent toughness and yield strength. Hence, the stainless steel can withstand high force exertion. Therefore, the stainless steel has been chosen as the main materials for the designed robot.

After choosing the materials for the robot, the simulation of the robot parts is proceeded next. The stress and strain simulation analysis are done on the robot parts and the results are analysed. This simulation is carried out to determine the strength of the parts based on the selected materials and the given force. The figure below shows the properties of the chosen materials:

Properties	
Name:	AISI 347 Annealed Stainless Steel (SS)
Model type:	Linear Elastic Isotropic
Default failure criterion:	Max von Mises Stress
Yield strength:	2.75e+08 N/m^2
Tensile strength:	6.55e+08 N/m^2
Elastic modulus:	1.95e+11 N/m^2
Poisson's ratio:	0.27
Mass density:	8000 kg/m^3
Shear modulus:	7.7e+10 N/m^2
Thermal expansion coefficient:	1.7e-05 /Kelvin

Figure 3.12: The Properties of the Stainless Steel

3.8 Simulation Analysis Description

The simulation analysis is done by using the SOLIDWORKS software

3.8.1 Stress and Strain Simulation

This simulation is done to determine the stress and strain of the robot parts of the Pipeline Inspection Robot.

Procedure:

1. The assembled part is open in SOLIDWORKS followed by Simulation Xpress.

2. A fixture is added by selecting the face model [inside hull] (show green arrows).

3. The load is added by applying a force or pressure to the particular area on the model [outside hull] (show purple arrows).

4. The stress and displacement is calculated by selecting a material to the part/body.

5. The mesh setting can be changed between cursor and fine and run the simulation.

7. Next, either to 'continue' or 'go back' to edit the study parameters

8. Click 'continue', the 'stress, displacement and factor of safety' will show out

9. Finally, the report can be generated in either Microsoft Word or *eDrawings* format.

3.9 Completion of the Designed Robot

After considering the desired design of the robot, completing the design and running the analysis and simulation on the robot, the design is finally completed. The next step would be the fabrication of the designed robot.

3.10 The Fabrication of the Pipeline Inspection Robot

Following the completion of the designed robot, the robot is ready to be fabricated with the desired specifications, measurements and design. Specific machineries are used to create the parts of the robot. Modifications of the specifications and measurements of the robot parts are also being made throughout the process of fabricating the Pipeline Inspection robot.

3.11 Experiment Description

3.11.1 Experiment 1: The Pipeline Inspection Robot Speed Test

Objective: To measure and determine the average speed of the Pipeline Inspection Robot in a 320mm length pipe with the diameter of 266mm

Parameters:
Manipulated Variable: Average speed, number of trials
Responding Variable: Time
Constant Variable: Distance

Apparatus: Pipeline Inspection Robot, a timer

Procedure:

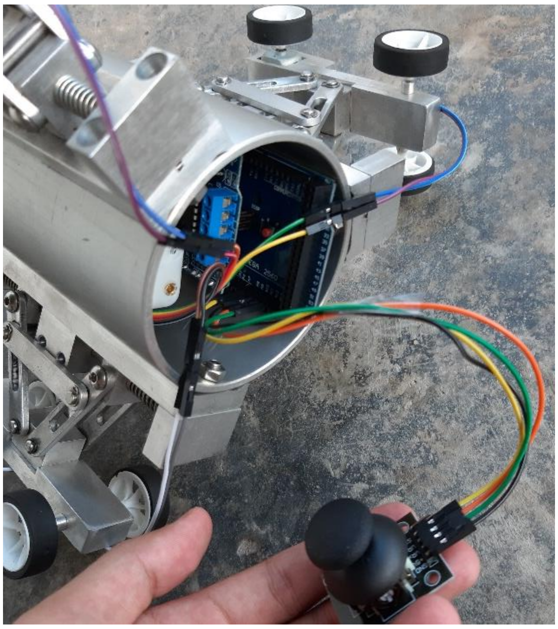


Figure 3.13: Setup of Experiment 1

Figure 3.14: The pipe used

1. A 1m pipeline with the diameter of 266mm is prepared.
2. The Pipeline Inspection Robot is put in the pipe.
3. The Pipeline Inspection Robot is tested to run a distance of 320mm controlled by the joystick in the designated pipe.

4. 10 trials are given to take the average speed of the Pipeline Inspection Robot.
5. Step 3 is repeated until all the trials are done.
6. The observation is recorded and tabulated in a table form.

3.11.2 Experiment 2: The Pipeline Inspection Robot Pipeline Diameter Adaptability Test

Objective: To determine the ability of the Pipeline Inspection Robot to adapt in changing pipe diameters.

Parameters: Manipulated Variable: Diameter of pipes

Responding Variable: The ability of the Pipeline Inspection Robot to adapt in pipe diameter changes

Constant Variable: The length of the pipes

Apparatus: Pipeline Inspection Robot, three straight pipes with a diameter of 220mm, 250mm, and 280mm with the same length of 500mm.

Procedure:

1. The 500mm length straight pipes with the diameters of 220mm, 250mm and 280mm is attached together forming a longer pipeline with different diameters.
2. The Pipeline Inspection Robot is put in the entrance of the long pipe.
3. The Pipeline Inspection Robot is moved forward to travel along the pipe changing diameters to observe its ability to expand and contract in the pipe
4. The observations are recorded and discussed.

3.11.3 Experiment 3: The Pipeline Inspection Robot Movement Accuracy Test

Objective: To observe the straightness of the Pipeline Inspection Robot movement in a pipeline

Parameters:

Manipulated Variable:	Number of trials, degree of starting position of the Pipeline Inspection Robot
Responding Variable:	The straightness of the lines produced by the Pipeline Inspection Robot
Constant Variable:	The length of the pipe, diameter of the pipe

Apparatus: Pipeline Inspection Robot, a pipe of diameter 266mm with the length of 320mm, 5m string, a marker pen, a 2inch C-clamp, and a plastic ruler

Procedure:

Figure 3.15: The Initial Position of the Marker Pen Tip

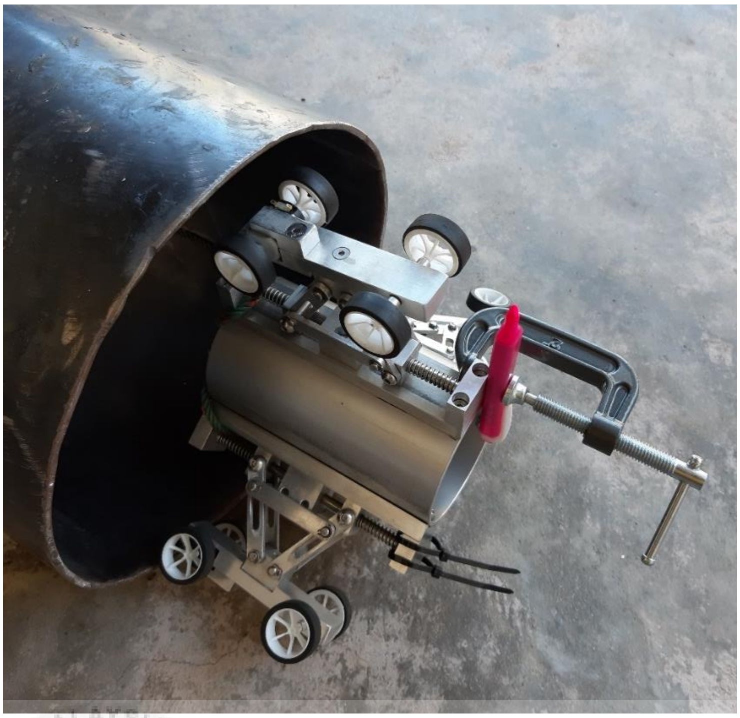


Figure 3.16: Setup of Experiment 3

1) The Pipeline Inspection Robot is prepared with the marker pen is attached to the robot by using a 2 inch C-clamp.
2) The Pipeline Inspection Robot is placed inside the entry of the pipe and the tip of the marker pen is adjusted to touch the surface of the inner pipe.
3) The robot is then controlled by the joystick to move inside the pipe.
4) The lines made by the marker pen is observed and recorded.
5) Steps 3 until 5 is repeated with 5 trials with a slight difference in the starting points to observe the straightness of the movement of the robot.
6) The observations are recorded in a table.

3.12 Summary

The methodology is described and discussed thoroughly. The basic design and the description of the Pipeline Inspection Robot is shown and discussed. Simulation analysis methods are described. Experiments to verify the performance of the Pipeline Inspection Robot are stated.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter discusses the analysis that have been done to the designed Pipeline Inspection Robot's parts and the fabricated Pipeline Inspection Robot. Further discussions of the chosen Pipeline Inspection Robot's design are discussed thoroughly. The fabricated Pipeline Inspection Robot specifications, measurement and modifications are analysed clearly in this chapter. The experimentations results are also presented in this chapter.

4.2 The Proposed Design of the Pipeline Inspection Robot

The Pipeline Inspection Robot design is basically based on the wheeled wall press type robot that is proposed by Y. Qu *et al*. (The Smart Spider). The complete design of the Pipeline Inspection Robot is shown in the different planes of view in the Figure 4.1, 4.2, and 4.3 respectively below. The robot that have been designed can fit a pipe diameter ranging from 90mm to 130mm. This robot applies the adaptive mechanism in which the spring tension acts as a passive support which enable the robot to keep intact to the pipe inner walls. Instead of applying the active stepper motor support which is implemented on the Smart Spider, this robot uses the spring tension as passive support as proposed by Atsushi Kakogawa et al. in their caterpillar wall press type robot. This design has much less complexity than both of the proposed designed robots (Y. Qu *et al*. and Atsushi Kakogawa *et al*.). The designed robot has a length of 15cm and the arms of the robot have a maximum reach of 130mm. The most contracted and expanded state of the robot arm are shown in the Figure 4.7 and 4.8 respectively. The body tube of the designed robot which act as the main body is used to store the electrical components. The designed robot uses stainless steel as its main materials that composed most of its parts. Stainless steel has been chosen mainly due to its ability to withstand corrosion and oxidation as this robot are going to be used to inspect pipelines which have various conditions. In addition, the front and the rear of the robot is attached with a transparent acrylic plastic respectively to protect the electrical components inside the body tube especially the camera that is used for inspecting the pipelines.

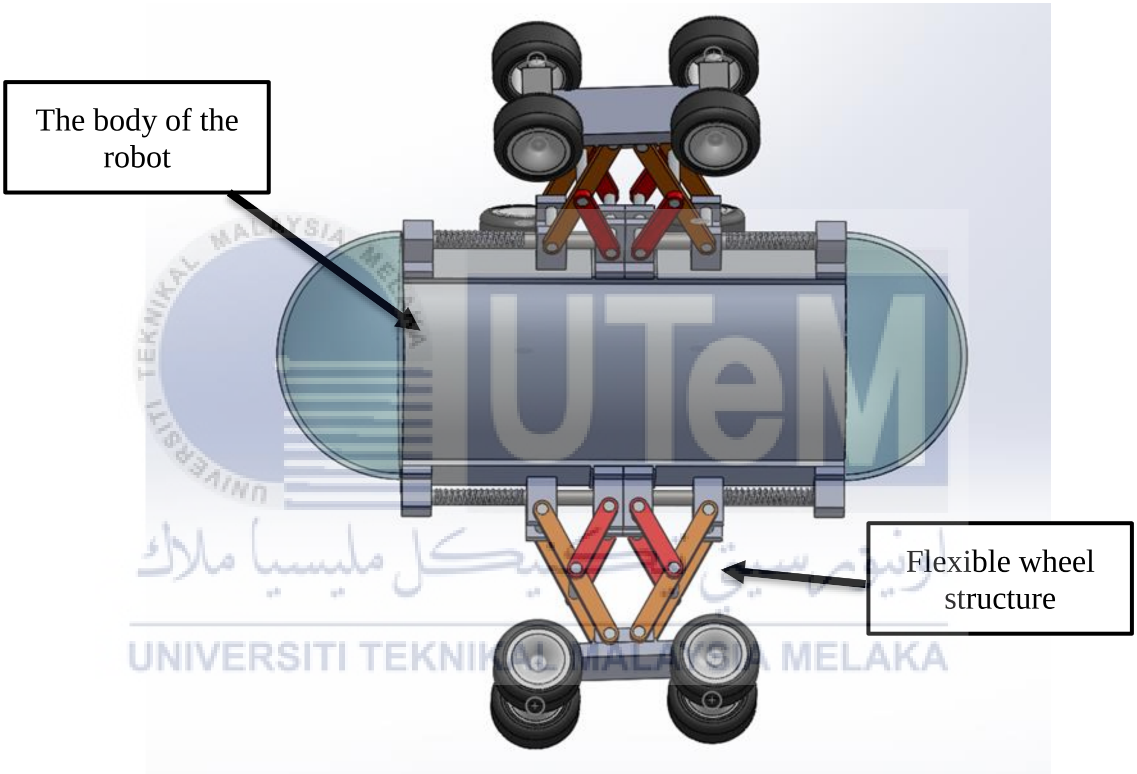


Figure 4.1: The Right Plane View of the Designed Pipeline Inspection Robot

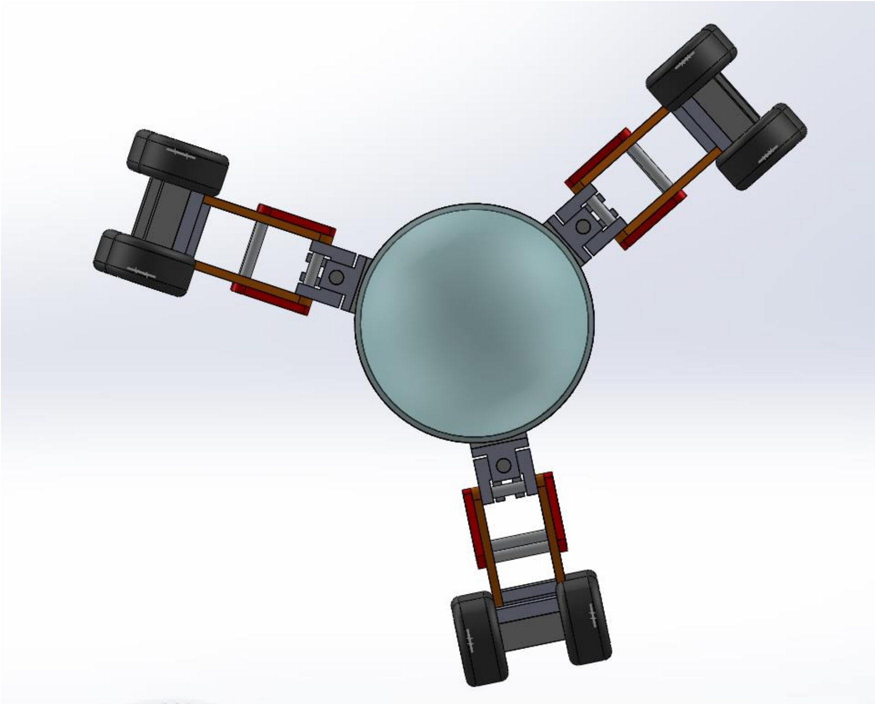


Figure 4.2: The Front Plane View of the Designed Pipeline Inspection Robot

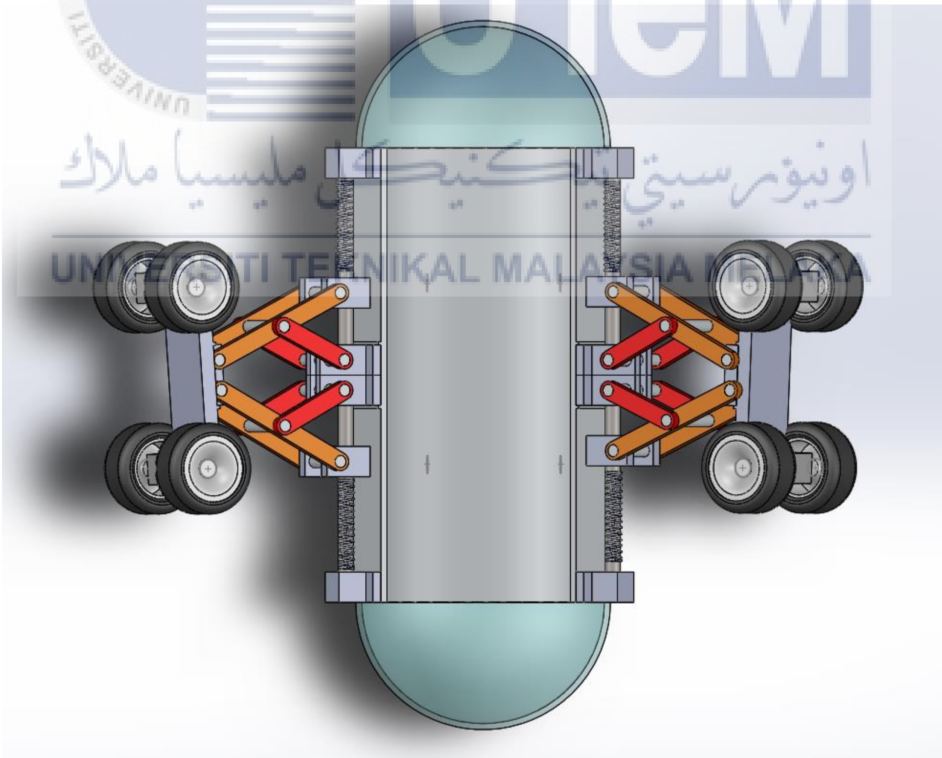


Figure 4.3: The Top Plane View of the Designed Pipeline Inspection Robot

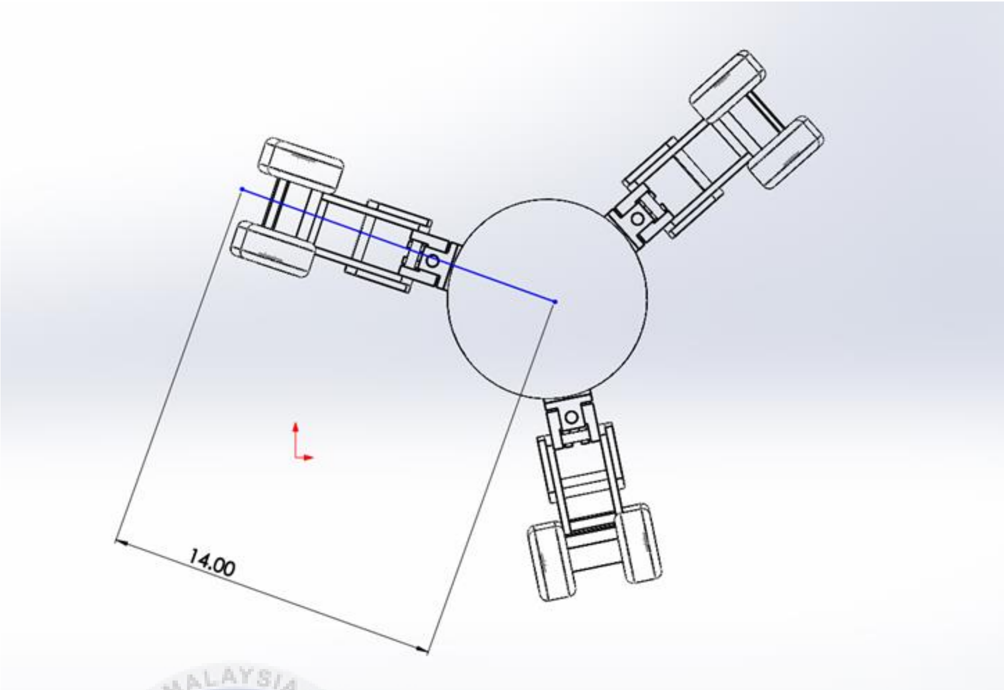


Figure 4.4: The Extended State of the Designed Pipeline Inspection Robot

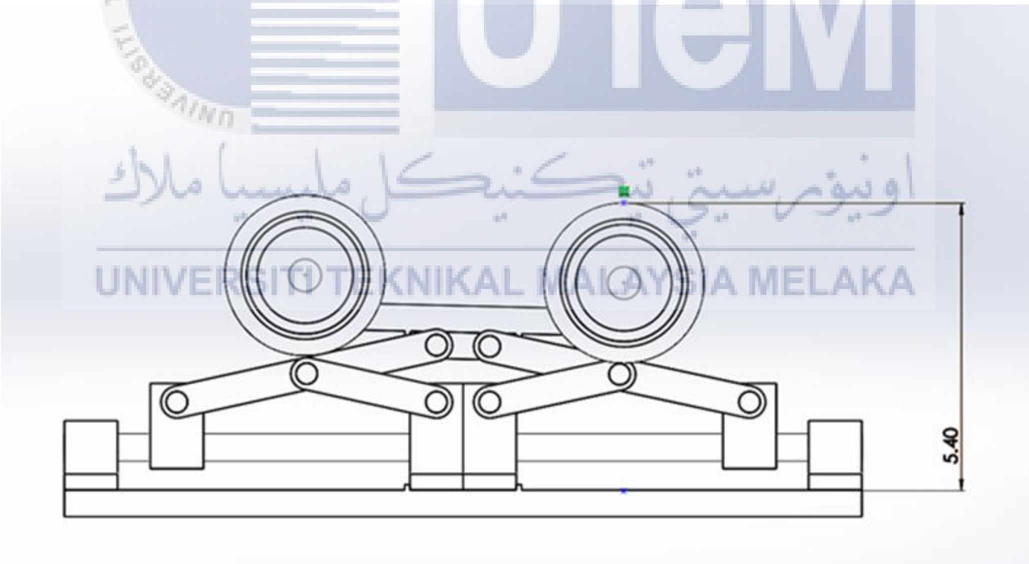


Figure 4.5: The Most Contracted State of the Four-Bar Linkage Adaptive Mechanism

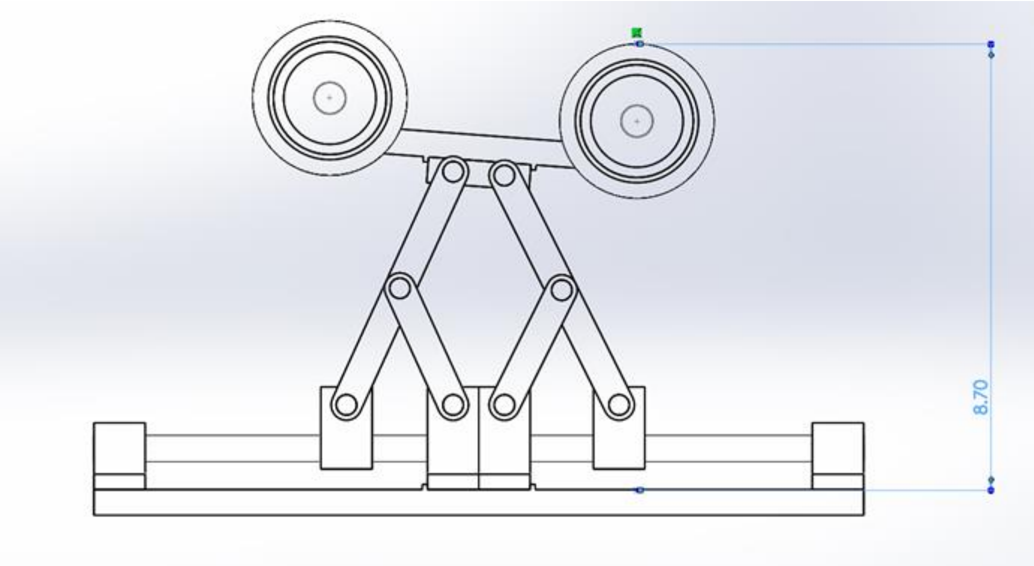


Figure 4.6: The Most Extended State of the Four-Bar Linkage Adaptive Mechanism

4.3 The Stress and Strain Analysis of the Designed Pipeline Inspection Robot

The stress and strain analysis results on the certain parts of the robot that have been done in the SOLIDWORKS software is shown in the figures below. All the parts are given the same amount of force which is 100N and are given the same type of materials which is the Annealed Stainless Steel. The Annealed Stainless Steel has a yield strength of 2.750e+8N/m^2. The maximum stress given by the 100N force to the Body Tube is 2.656e+5N/m^2 which is lower than the yield strength of the material. Therefore, the body tube is operating within safe limits because the maximum stress is below the amount of the yield strength. Yield strength is calculated by using the following formula:

$$\sigma = \frac{N_{yield}}{A} \tag{4.1}$$

Where σ is the yield strength, N_{yield} is the yield load in Newton and A is the cross-sectional area in mm^2.

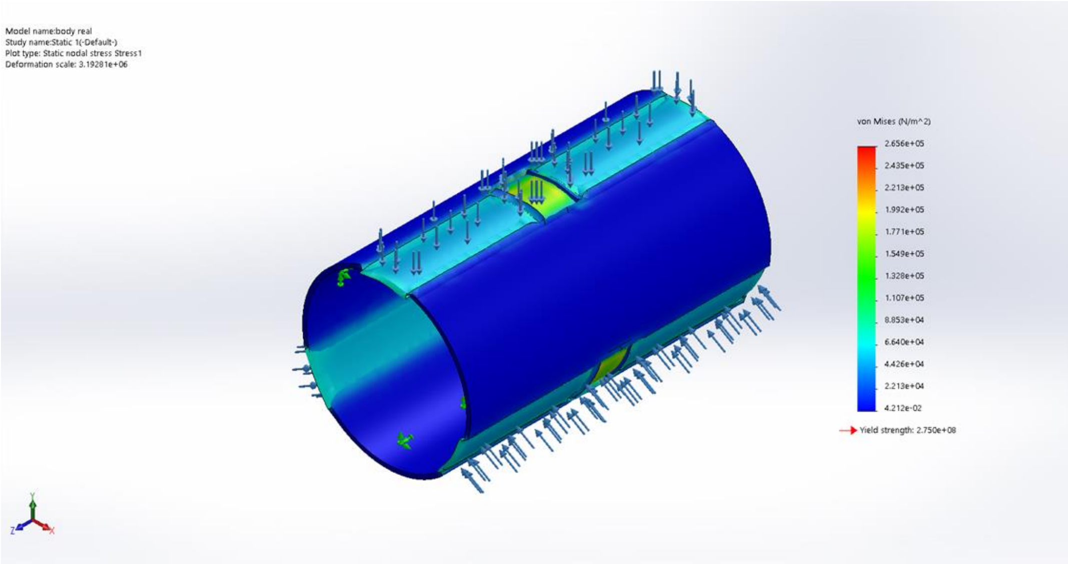


Figure 4.7: The Stress Analysis on the Body Tube

As mentioned earlier, all the parts are given the same amount of force and materials which is 100N and Annealed Stainless Steel. The robot part as shown in the Figure 4.5 below has the yield strength of 2.750e+8N/m^2 and the maximum stress given by the 100N force is 4.325e+68N/m^2 which is lower than the yield strength. Therefore, this part of the robot operates within the safe limit.

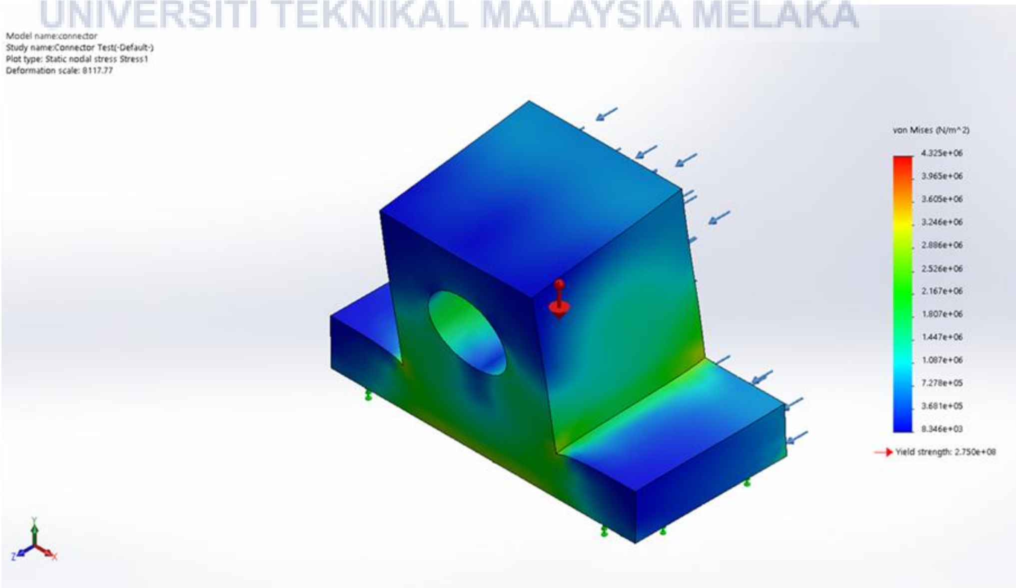


Figure 4.8: The Stress Analysis on the Connector

Same goes to the two robot parts in the Figure 4.6 below, they are operating within the safe limits because the maximum stress given is below the yield strength of the parts.

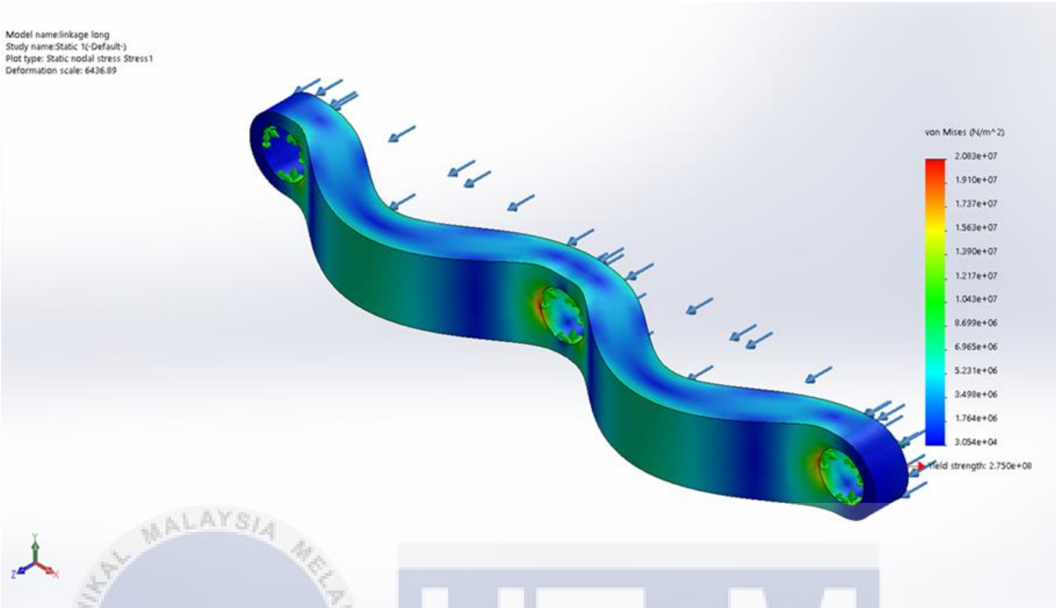


Figure 4.9: The Stress Analysis on the Parts of the Four-Bar Linkage

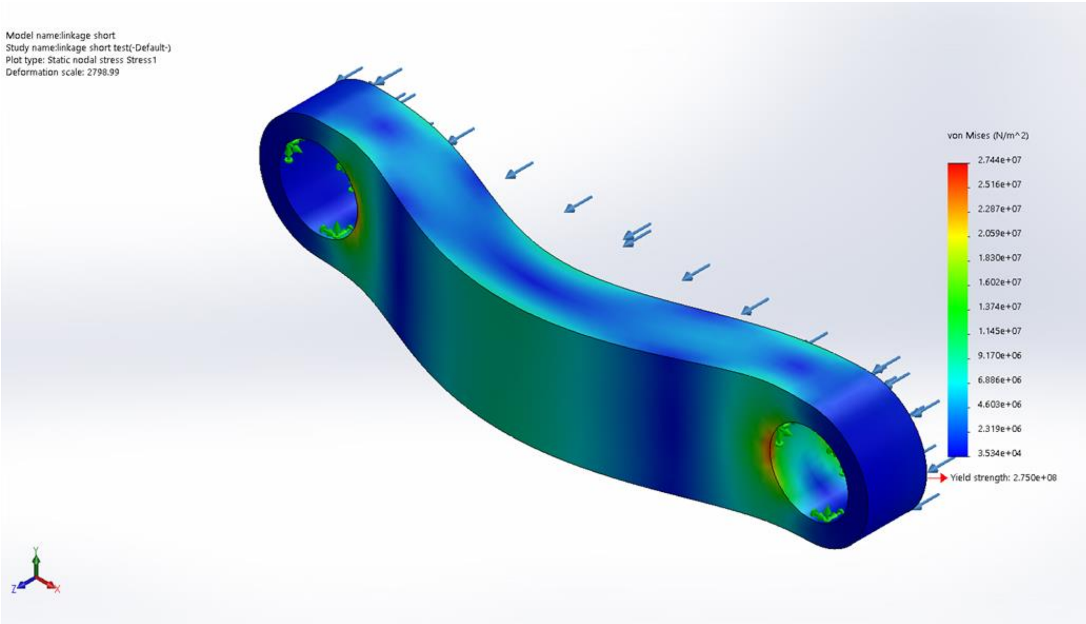


Figure 4.10: The Stress Analysis on the Parts of the Four-Bar Linkage

4.4 The Fabricated Pipeline Inspection Robot

Figure 4.11 to 4.17 shows the Pipeline Inspection Robot that has been fabricated. As mentioned earlier, this robot is based on the wheeled wall press type robot that is proposed by Y. Qu et al. (The Smart Spider) but using springs as passive supports instead of stepper motors to decrease the robot's complexity. A few modifications and specifications have been made to the fabricated Pipeline Inspection Robot throughout the fabrication process. The specifications and the measurements of the fabricated robot is shown in the Table 4.1.

Table 4.1: The Specifications and Measurements of the Fabricated Pipeline Inspection Robot

Robot Length (mm)		150
Robot Weight (Kg)		2.2
Maximum Adaptive Diameter (mm)		280
Minimum Adaptive Diameter (mm)		215
Diameter without the spring attached (mm)		200
Wheels Diameter (mm)		30
Average Speed		0.0096m/s

The differences between the designed and the fabricated Pipeline Inspection Robot are mainly on the adaptive mechanism linkage which connect to the wheels of the robot. The changes are made because the measurements of the adaptive mechanism parts of the designed robot are too small and thus, it was impossible to be fabricated. The changes in the measurements led to the increase of the maximum extended state diameter and the minimum extended diameter of the Pipeline Inspection Robot. Hence, pipes with bigger diameter are needed to analyse the performance of the fabricated Pipeline Inspection Robot.

On the other hand, the changes in measurements also led to the increase of the robot's weight. The robot is quite heavy with the weight of 2.2kg. The robot's weight was not expected to be heavier than we thought after the fabrications and thus the DC motors that are used to move the robot did not have enough power to move the robot sufficiently. The speed of the robot is rather slow with an average speed of 0.0096m/s. Thus, further modifications of the fabricated Pipeline Inspection Robot and recommendations will be made and stated for future works to improve the robot's driving speed.

The materials that are used to make the Pipeline Inspection Robot parts are entirely aluminiums. Aluminiums have a very low specific weight of about 1/3 of iron. Hence, this can decrease the robot's weight than using common metals to fabricate the robot. Furthermore, aluminium have a very high resistant against corrosion and oxidation which best to be used for the Pipeline Inspection Robot as the robot will be used and travel inside a pipeline with various conditions. Despite the beneficial properties of the aluminium, the fabricated Pipeline Inspection Robot turns out quiet heavy and thus, further research and development will be made to the robot for future works and studies.

Next, the transparent body covers for the front and backside of the Pipeline Inspection Robot were not be able to complete because of time constraint. The fabrications, modifications and the assembly of the fabricated Pipeline Inspection Robot took tremendous amount of time. The designed body covers that are made up of acrylic plastic are used to protect the electronic parts inside the body of the robot. It also protects the camera that will be placed inside the robot's body for inspection utilizations.

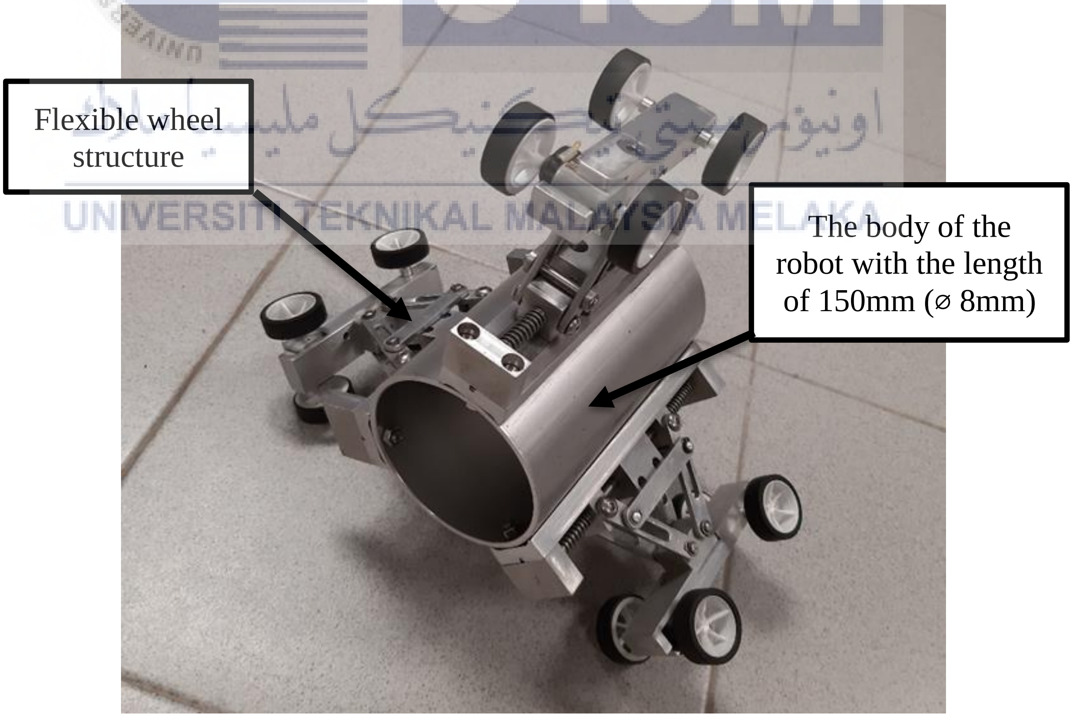


Figure 4.11: The Fabricated Pipeline Inspection Robot

Figure 4.12: The Front View of the Fabricated Pipeline Inspection Robot

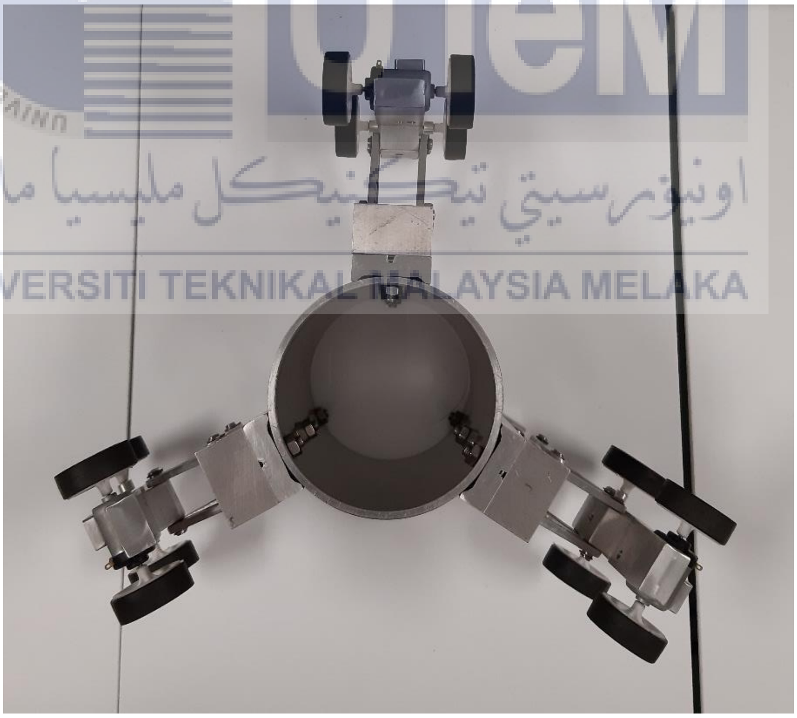


Figure 4.13: The Top View of the Fabricated Pipeline Inspection Robot

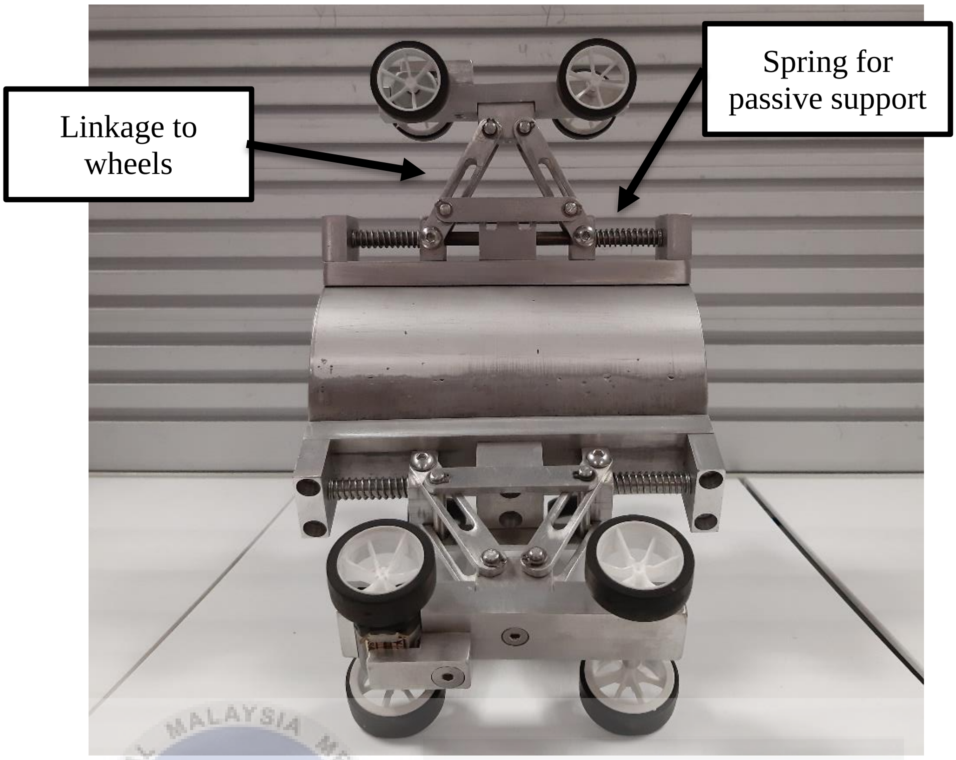


Figure 4.14: The Right View of the Pipeline Inspection Robot

Figure 4.15: The Most Expanded State of the Pipeline Inspection Robot

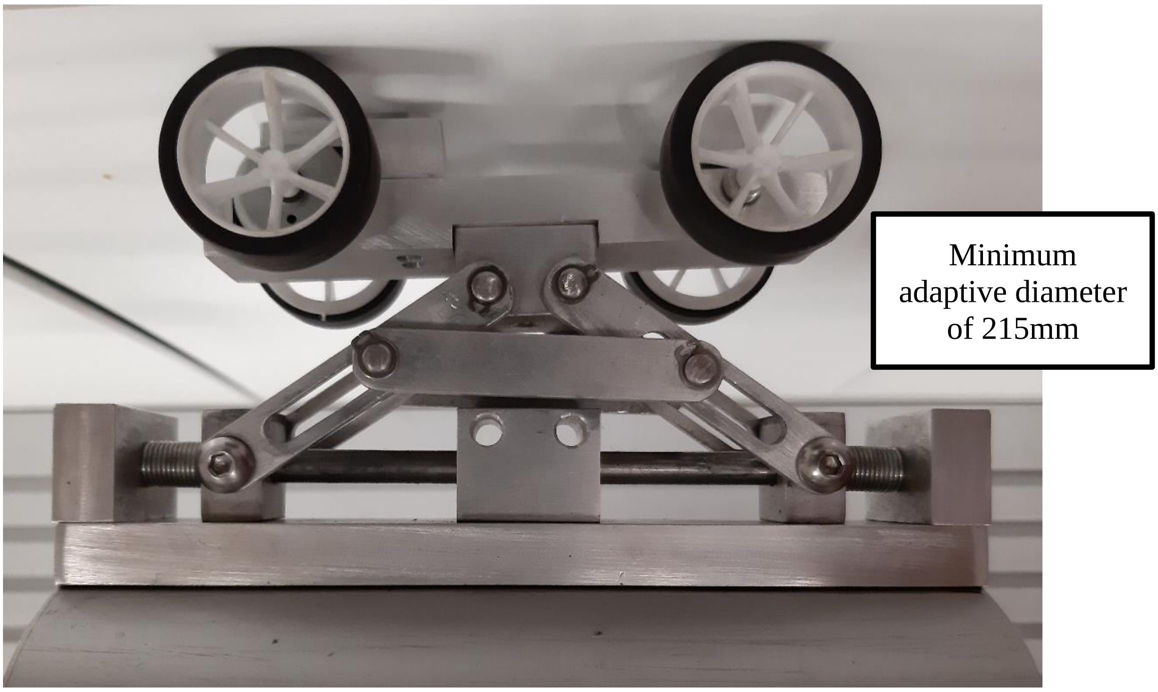


Figure 4.16: The Most Contracted State of the Pipeline Inspection Robot

Figure 4.17: Close up View of the Adaptive Mechanism of the Pipeline Inspection Robot

4.5 The Analysis and Discussion of the Experiments

4.5.1 The Pipeline Inspection Robot Speed Test

The experiment is prepared to analyse and observe the robot's average speed in a 320mm length pipe with the diameter of 266mm. A number of 10 trials were done to test the robot's speed inside the pipe and the time for the robot to move inside the pipe and the average speed is recorded in the table 4.2 below.

Table 4.2: The Results of the Pipeline Inspection Robot Speed Test

Trials	**Time taken to move inside the 320mm length 266mm diameter pipe (s)**
1	31
2	33
3	35
4	31
5	34
6	33
7	32
8	35
9	36
10	32
Average time to move to the end of the pipe	33.2
Average speed of the robot	**0.0096m/s**

The robot took an average of 33.2s to move to the end of the 320mm length pipe and gain an average speed of 0.0096m/s. The average speed of the robot was calculated by using the following formula:

$$v_{avg} = \frac{d}{t_{avg}} \tag{4.2}$$

Where v_{avg} is the average speed, d is the distance travelled and t_{avg} is the average time taken for the robot to travelled along the distance. The performance of the robot's speed can be further improved with proper modifications and future works.

4.5.2 The Pipeline Inspection Robot Pipeline Diameter Adaptability Test

This experiment was not able to proceed as the desired pipes with the desired diameters were not available to be used in this experiment.

4.5.3 The Pipeline Inspection Robot Movement Accuracy Test

This experiment is prepared to analyse the straightness of the movement of the Pipeline Inspection Robot inside a pipe of 266mm diameter with the length of 320mm. To analyse the robot's movement straightness inside the pipe, a marker pen is clamped to the robot by using a C-clamp and the robot will move along with the clamped marker. The marker pen's line produced by the robot will determined the robot's straightness in movement inside the pipe.

Figure 4.18: The Line Produced by the Pipeline Inspection Robot with 5 Trials

4.5.3.1 Trial 1

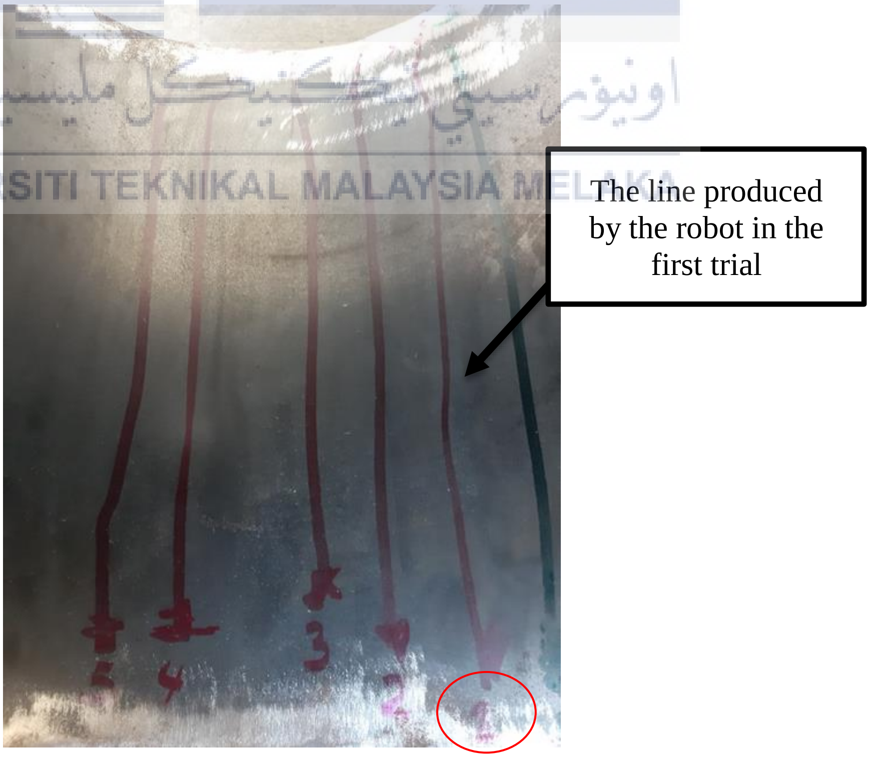


Figure 4.19: The First Trial Result

The diameter of the pipe is 266mm and the Pipeline Inspection Robot have the most extended state of the flexible arm of 280mm. Hence, once entering the 266mm diameter pipe, the Pipeline Inspection Robot flexible arms are contracted to adjust to the size of the inner pipe. Due to the robot's heavy weight, the springs used were able to withstand the robot's load without deforming. Hence, the grip force produced by the flexible arms inside the 266mm pipe is quite strong making the robot to be able to grip its position inside the pipe.

Once prepared and attached a marker pen by using a C-clamp to the robot, the robot is moved by controlling it using the joystick until it reached the end of the pipe. It is observed that the line produced on the first trial is not perfectly straight but still maintain its path until the end of the pipe. The lines produced are quite the same or better in the next four trials. The robot can maintain its path along the pipe without slipping inside the pipe.

4.5.3.2 Trial 2

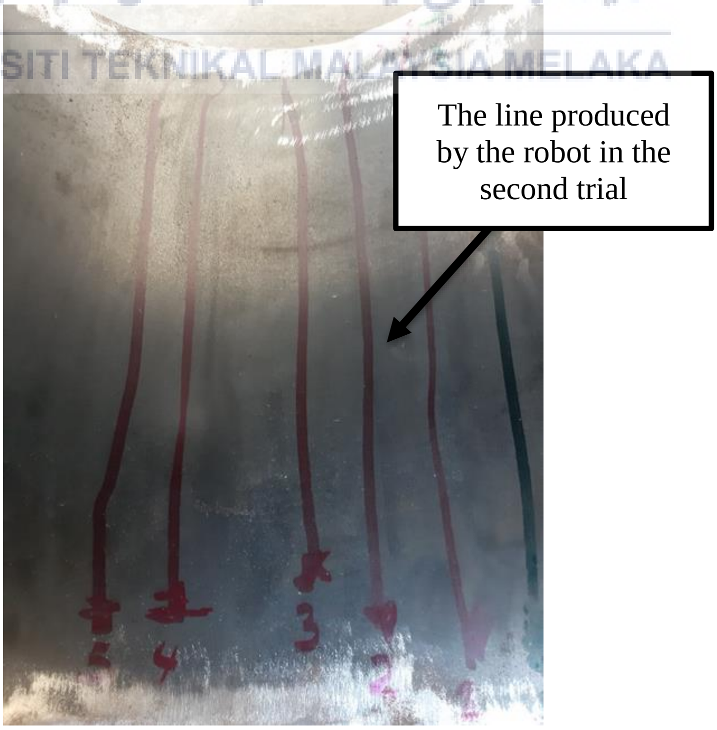


Figure 4.20: The Second Trial Result

4.5.3.3 Trial 3

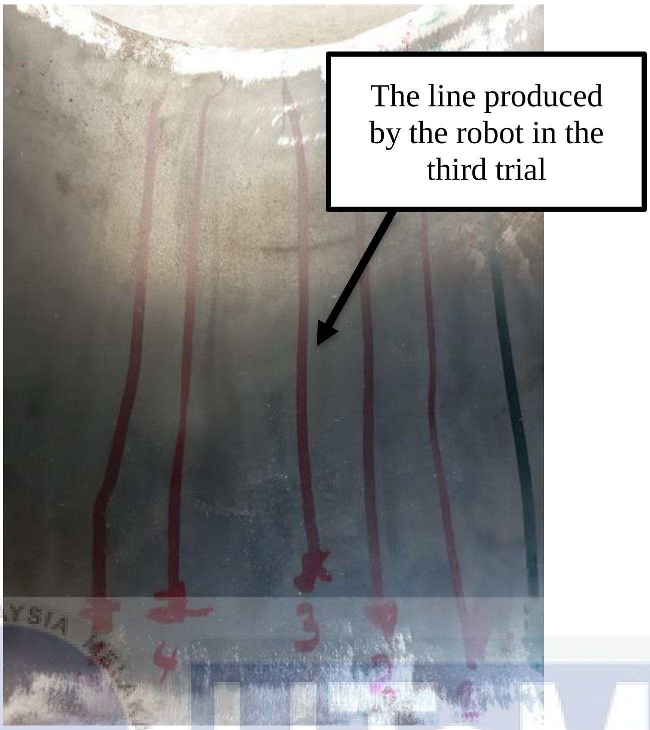


Figure 4.21: The Third Trial Result

4.5.3.4 Trial 4

Figure 4.22: The Fourth Trial Result

4.5.3.5 Trial 5

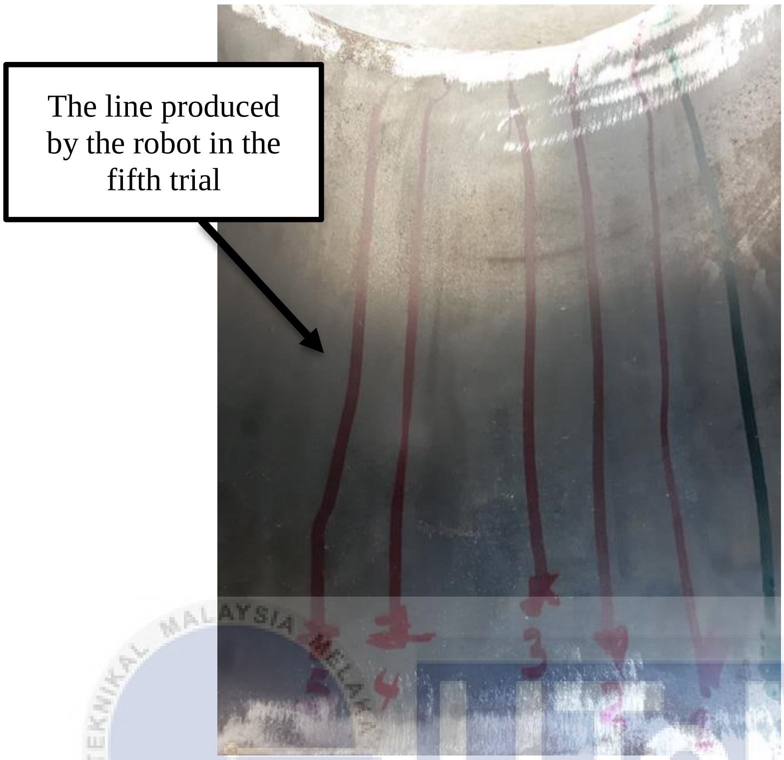


Figure 4.23: The Fifth Trial Result

Table 4.3: The Overall Results of the Five Trials

Trials	Observations
1	The robot is able to move straight with a slight observable bend line
2	The robot is able to move straight with a near perfectly straight line
3	The robot is able to move straight with a slight bend in the starting point of the pipe and the exit point of the pipe
4	The robot is able to move straight with a near perfectly straight line
5	The robot is able to move straight with a slight bend line on the starting point

All the observations are successfully recorded into the table. Although the second experiment was not able to be done, the robot has shown its performances in the experiment 1 and 3. Future works and recommendation will be implemented on the Pipeline Inspection Robot to improve its performance and further analyse its capabilities.

4.6 Summary

In this chapter, the Pipeline Inspection Robot has been designed successfully and the first objective of this research is achieved. Next, the Pipeline Inspection Robot is able to be fabricated and thus the second objective is accomplished. The second experiment was not able to be carried out because of the unavailability of the desired pipes. Nevertheless, the performances of the robot were able to be analysed and observed in the experiment 1 and 2 and thus, the third objective of this project is achieved.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

As a conclusion, the objectives of this Final Year Project have been achieved. The design of the Pipeline Inspection Robot with the specifications and features have been done successfully. Next, the fabrications of the robot are also a success although there were a few modifications that have been made to the measurements and specifications of the PIR. The performance of the PIR in terms of flexibility can be further analyse with proper modifications to the Pipeline Inspection Robot.

For the completion of the project, more than 30 articles and journals regarding the design and development of the PIR have been reviewed and studied. Useful data and information are extracted from the papers and are applied to the project carefully. The best design and specifications for the PIR have been chosen based on these papers. Throughout the fabrication process, a few changes in measurements were made to the parts of the robot because some parts are too small to be fabricated. These changes were carefully made and the robot is fabricated successfully. There was unexpected result made after the fabrications of the robot. The weight of the robot was unexpectedly heavy and it affected the speed of the robot.

Throughout this project, various types of pipeline robots were studied and their movement mechanism have been reviewed. Furthermore, different types of microcontroller have also been analysed and chosen. The skills and knowledge needed to use the *SOLIDWORKS* software to design the PIR have been improved. A part from that, the skills to write the Arduino coding are also improved as well.

5.2 Future Works and Recommendations

For the recommendations of this project, firstly, to improve the speed of the robot, the DC motor have to be changed and thus, a modification has to be made to the robot wheels due to the lack of torque in the installed DC motors. To installed a different kind of DC motors, modifications have to be made to the wheels part as shown in the diagram below.

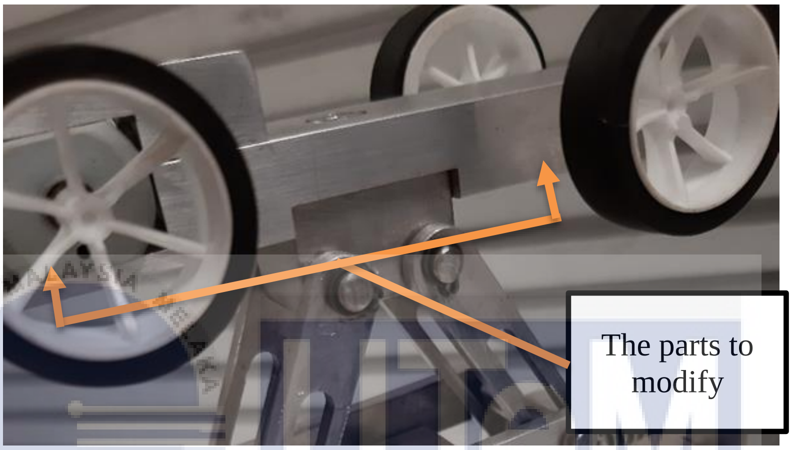


Figure 5.1: The Part of the Robot to Modify

The wheels plating of the fabricated Pipeline Inspection Robot was made for the Mini 4WD Atomic Tuned Motor Pro DC Motor. Recommended DC motors to be used in future works are the 12V 430RPM 1kgfcm 32mm Planetary DC Geared Motor as shown in the Figure 5.2.

Figure 5.2: The 12V 430RPM 1kgfcm 32mm Planetary DC Geared Motor

To use this DC geared motor, a new wheel's structure has to be designed and fabricated to fit the recommended DC geared motor. Moreover, bigger wheels are also needed to fit the DC geared motors with the wheels. To connect the wheels with the DC geared motors a worm gear and pinion assembly is needed. The Figure 5.3 below shows the example of the worm gear and pinion assembly. The worm gear and pinion are used to connect the DC geared motor with the wheels and to increase the compatibility of the worm gear and pinion with the wheels, they can be designed in the *SOLIDWORKS* software and fabricated by using a 3D printer.

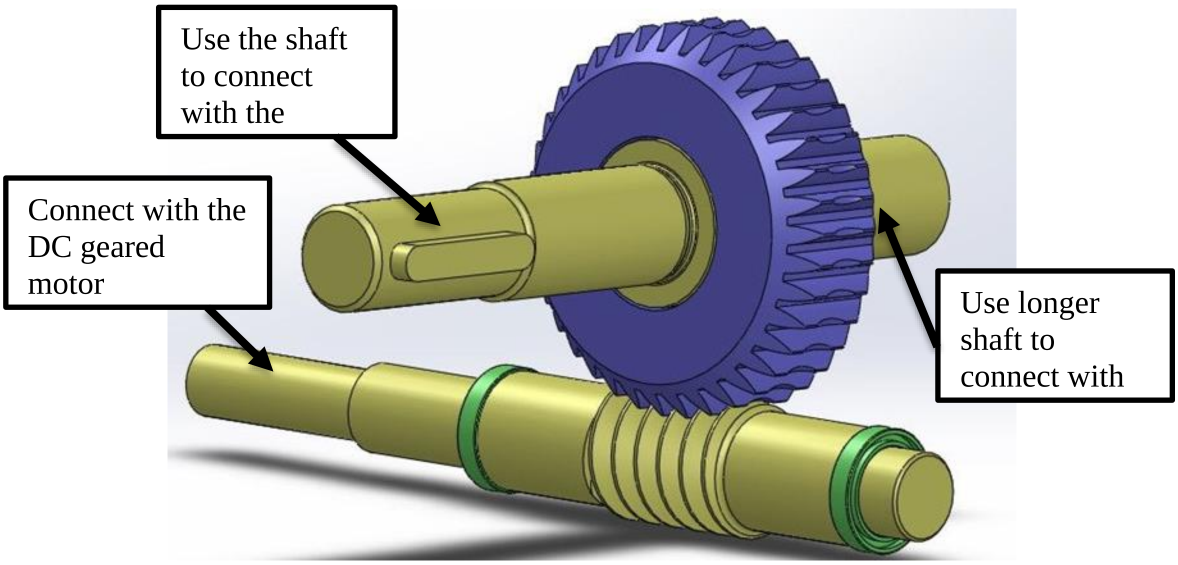


Figure 5.3: The Example of Worm Gear and Pinion

Furthermore, another future work that can be done is changing the springs specification that are used as the passive support on the Pipeline Inspection Robot. The current spring enables the robot to compress to a pipe diameter of 220mm while without the usage of the spring, the robot can fit inside a pipe diameter of 190mm. The current spring has a length of 40mm with 14 coils. By reducing the number of coils on the spring the Pipeline Inspection Robot can be further compress its diameter and increase its adaptability inside a pipeline.

After the completion of all the modifications and improvements, the Pipeline Inspection Robot can be further equipped with the CCD camera to analyse its inspection performance. Through this analysis, the robot can advance to serve its purposes as a Pipeline Inspection Robot in industrial area.

As a conclusion, there are many ways to improve the Pipeline Inspection Robot in terms of its performance and design. To increase and improvise the performance of the robot, these future works are needed and further develop this Pipeline Inspection Robot.

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APPENDICES

APPENDIX A GANTT CHART OF FYP

Project Activities of FYP 1	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Project Activities of FYP 1	■													
Project Prospect Discussion with Supervisor	■	■												
Journal/ Research Paper Review			■	■	■	■								
Literature Review					■	■	■	■						
Methodology Outline							■	■	■	■				
Robot Designs Selection					■	■								
Design and Assembly in SOLIDWORKS							■	■	■					
SOLIDWORKS Analysis and Simulation								■	■					
Components Selection									■	■				
Data Collection and Analysis										■	■			
FYP 1 Report Writing								■	■	■	■	■	■	■
FYP 1 Presentation and Report Submission												■	■	

Project Activities of FYP 2	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Fabrications of Hardware	■	■	■											
Components Integratrion		■	■											
Software Development			■	■										
Hardware Testing and Troubleshooting				■	■									
Design and Conduct Experiment						■	■	■						
Data Collection and Simulation						■	■	■						
Data Analysis									■	■	■	■		
Report Writing									■	■	■	■		
FYP 2 Presentation and Report Submission													■	■

APPENDIX B ARDUINO CODING (FORWARD AND REVERSE)

```
#define enA 9
#define in1 6
#define in2 7
#define button 4
int rotDirection = 0;
int pressed = false;
void setup() {
  pinMode(enA, OUTPUT);
  pinMode(in1, OUTPUT);
  pinMode(in2, OUTPUT);
  pinMode(button, INPUT);
  //
  digitalWrite(in1, LOW);
  digitalWrite(in2, HIGH);
}
void loop() {
  int potValue = analogRead(A0); //
  int pwmOutput = map(potValue, 0, 1023, 0 , 255); // to 255
  analogWrite(enA, pwmOutput); //
  // Read button - Debounce
  if (digitalRead(button) == true) {
    pressed = !pressed;
  }
  while (digitalRead(button) == true);
  delay(20);
  // If button is pressed - change rotation direction
  if (pressed == true  & rotDirection == 0) {
    digitalWrite(in1, HIGH);
    digitalWrite(in2, LOW);
    rotDirection = 1;
    delay(20);
  }
  //
  if (pressed == false & rotDirection == 1) {
    digitalWrite(in1, LOW);
    digitalWrite(in2, HIGH);
    rotDirection = 0;
    delay(20);
  }
}
```

APPENDIX C L293D MOTOR DRIVER SCHEMATIC