DEVELOPMENT OF LINKAGE MECHANSIM FOR IN-PIPE ROBOT

By:

TEOH CHEE HAW

(Matrix no: 125431)

Supervisor:

DR. NORZALILAH MOHAMAD NOR

JUNE 2018

This dissertation is submitted to

Universiti Sains Malaysia

As partial fulfilment of the requirement to graduate with honours degree in

BACHELOR OF ENGINEERING (MANUFACTURING ENGINEERING WITH MANAGEMENT)

School of Mechanical Engineering

Engineering Campus

Universiti Sains Malaysia

DECLARATION

This thesis is original research work form me. This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree. All the work is under supervisor by Dr. Norzalilah Mohamad Nor, at the Universiti Sains Malaysia.

Signed: ………………………………………………………… (TEOH CHEE HAW)

Date:

In my capacity as supervisor of the candidate's thesis, I certify that the above statements are true to the best of my knowledge.

Signed: …………………………………… (DR. NORZALILAH MOHAMAD NOR)

Date:

ACKNOWLEDGEMENT

First of all, I would like to give my deepest gratitude towards Universiti Sains Malaysia (USM) for giving me the opportunity to pursue a Bachelor’s Degree in Manufacturing Engineering with Management. Many people had help me throughout this one year to make this Final Year Project (FYP) a success.

Next, I would like to thank my supervisor, Dr Norzalilah Mohammad Nor for her guidance on how to conduct the research project, and her advice on solving the encountered challenges. I had also learnt many things from her under her supervision. Without her guidance, this project will not be able to complete in time.

Besides, I would like to sincerely thank the assistance engineers of the School of Mechanical Engineering, particularly Mr. Norijas and Mr. Halim for their help and advice on how to handle safely the machine. With their help, the prototype for the robot was successfully fabricated in time.

Finally, I would like to thank my family and my friend for their advices and motivations on the management of FYP from the start until the end.

CONTENTS

LIST OF FIGURE

LIST OF TABLES

NOMENCLECTURE

F_s	Friction force	N
F	Forward force	N
W_h	Body Weight	N
A	Acceleration	m/s/s
F_s	Spring Force	N
k	Spring constant	N/m
P	Power	Watt
V	Voltage	V
I	Current	A

ABBREVIATIONS

CAD	Computer Aided Design
PIG	Pipe Inspection Gauges
3D	Three Dimension
DC	Direct Current
IC	Integrated Circuit
SPP	Serial Port Protocol
PWM	Pulse Width Modulation
PVC	Polyvinyl Chloride

ABSTRAK

Secara konvensional, pemantauan keadaan talian paip dilakukan oleh pekerja dan tidak dapat siap dalam masa satu hari. Proses pemantauan ini dilakukan secara berterusan. Sebagai penyelesaian masalah ini, robot dalam paip ini amat penting. Robot ini menjadikan pilihan utama untuk mengantikan pekerja melakukan kerja pemantauan kerana ia dapat melakukan dengan baik.

Tujuan projek ini adalah untuk merekabentuk dan menghasilkan robot dalam paip yang dapat begerak dalam paip yang bebeza saiz. Reka bentuk robot ini termasuk mechanisme bagaimana robot bergerak (Locomotion), elektrik (pendawaian), bentuk atau berat robot dan juga pengaturcaraan. Setiap aspek penting kerana ia akan mempengaruhi prestasi dan kecekapan robot.

Reka bentuk robot dalam paip ini adalah bahagian depan robot ini fleksibel. Ini disebakan reka bentuk ini dapat menyebabkan robot membuat putaran dalam paip. Robot ini terdiri daripada tiga motor 6V untuk menggerak dalam paip. Robot dalam paip ini dihasikan. Robot dalam paip ini dapat berpusing ke kanan ataupun ke kiri dengan mengawal arah kedua motor menurui kaji.

ABSTRACT

Conventionally, the monitoring of pipeline for leakage detection is done by workers and is not done within a day. This process instead is done continuously. As the solution of this problem, in-pipe robot had been invented. This robot is proven to be a better choice as it able to perform better than the workers.

The purpose of this project is to design and to fabrication an in-pipe robot which have high mobility in pipe of various size. The design includes the mechanism of how the robot moving (Locomotion), electrical (wiring), the shape or weight of the robot and also the programming. Each of the aspects are essential as it will affect the performance and the efficiency of the robot.

The final design of the in-pipe robot is a robot that is attached with a flexible front wheel. This design able to cause the robot to make a turn in the pipe. The robot also comprises of only three 6V motors to moving un the pipe. The kinematic model of the in-pipe robot is driven and the prototype has been developed. The in-pipe robot will able to turn either left or right by controlling the direction of the motor. The performance of the robot will then be verified by experimentation. The robot able to turn in the T-shape pipe by controlling the direction of the motor.

CHAPTER 1: INTRODUCTION

1.1 Introduction

Pipeline infrastructures are very important to society. Pipeline using as the transportation system to transport the water, natural gas, chemical and oil, but the most significant disadvantage is the leakages of pipe. To avoid the leakages of their pipeline, the In-pipe robot is the good solution to displace the human to inspect the condition in the pipe. Leakage of pipe is not distributing the problem with the economic issue only, but also an environment, sustainability and potentially health and safety issue [11].

Now a day, there have a various size of diameter of piping, pipeline may on the vertical and horizontal position and connection of the pipeline will connect using the "T-branch" or the curve radius pipe. So that, they got the challenges to the design the in-pipe robot which can be fulfilled to that difference type of pipe. To move the in-pipe robot to vertical direction, the easy way can be using the high torque of motor but in the aspect of energy conservation, production cost will high to invest.

The robot can be sort into two type of locomotion which is the active locomotive and passive locomotion. Active locomotion is mean that the robot can move in the pipe with actively move and accurately control the speed as well as the direction by carrying driving source. While for the passive locomotion means that the robot is difficult to control their locomotion speed and area because of no ability of active motion. In-pipe robot with the passive locomotion moving due to the flow of the liquid inside the pipe [10].

Many types of in-pipe robot are designing and selling in the market which is the pipe inspection gauge (PIG) type, wheel type, caterpillar type, wall-press type, walking type and screw type. Each type of robot got their advantage and disadvantage. Example the PIG type not equipped with any motor and it just using the flow in the pipe. The disadvantage of caterpillar type not had the ability to move in the vertical pipe lines [10]. The differential-drive type of mechanisms still has been studied which controlling the speed of the motor, the robot can move in all type of motor.

1.2 Project Background

In-pipe robot is design to move in the pipe and inspection on the situation of the pipe. This will easy for a maintained worker to found that which area of the pipes are broken. The broken of the pipe will cause many environment issue that need to be fixed immediately. Example, the pipe that transfer the chemical substance and oil that leakage will affect the chemical substance damage the environment pollution and excessive loss of material [10].

On the other hand, if the damage inside the pipelines cause by chemical rust, natural disaster will increase the difficulty to find out which the origin location. To put the sensor along the pipelines to detect the leakage was involved the higher cost, so that the in-pipe robot is the best solution on this movement. The study on the in-pipe robot to moving in a various size of diameter at any condition is very important. The mechanism of the robot moving in the pipe and the changing the size of the robot to fix into the various size of the pipe will be important.

Next, in-pipe robot will displace the human work to inspect and maintenance in the pipe. Because of the dangerous environment inside the pipeline, the in-pipe robot was the better choice to displace the human. Therefore, in-pipe robots need to be study. The design of the in-pipe robot involves the mechanism of the robot moving (Locomotion), electrical (wiring), the shape/weight of the robot and programming. Each of the aspect of the design will affect the performance and efficiency of the robot.

In the previous project, the robot is design based on the umbrella mechanism. This umbrella mechanism consists of a structure to make the robot adjust the height to adapt to various sizes of the pipe diameter. The robot cannot be moving in the T-shape pipe only can move forward and backward only. The design still has a few of the limitation need to be discovered.

1.3 Problem Statement

From the previous research in the School of Mechanical Engineering USM with the title of design of in-pipe mobile robot with adjustable links, there have the limitation in this project. In this project the in-pipe mobile robot cannot be turning in the bending pipe and the wheel in front of the robot are not stable enough to hold the wall in pipe. Beside that among the journal that found, there are very limited literature focussing to make the robot turning in the T-shape of pipes, only two of the journals are making the robot turning in the pipe which in the part of literature review 7 and 8. Therefore, the main objective of the present paper in to make the mechanism to a robot to make the turning motion in the T-branch pipe and making the front wheel more stabilize.

1.4 Objective

The project carries out with few objectives that listed below:

1. To build an in-pipe robot which it able to turn in the “T-Shape” pipe.
2. To stabilizing the in-front robot wheel.

1.5 Project Scope

Project scope will show in the table below:

Table 1.5 Scope of the project

Scope	Description
Study the current situation	-Read the literature review that related with the in-pipe robot. -Understanding the situation. -Important of the in-pipe robot to our world. -Identify the type of locomotion of the in-pipe robot.
Analysis the existing in-pipe robot	-Understanding the disadvantage of the existing in-pipe robot. -Come out with the problem statement and objective. -Study on the mechanism that move in the pipe.
Design the current situation	-Sketch/Build the 3D model using the computer aided design (CAD) software which is SolidWorks software. -There have many considerations when design the in-pipe robot: 1. Power consumption of the robot 2. Force for that motor to lift out the robot. 3. Mechanism to make the robot turning when in the junction of the pipe. 4. Control System using to control the robot.

Fabrication of the prototype	-Build the prototype with using the source that in the USM mechanical school. -Estimated the cost using to fabrication one of in-pipe robot.
Testing/ Experiment	-Testing the build prototype with the T-shape pipe with the 21.6mm diameter.
Analysis the result	-Analyse the robot turning -Identify the future work

To study on the locomotion of the robot for turning and stability of in-front robot wheel is the main objective to my project. In the previous in-pipe robot, the bottom part of the robot will be using the umbrella mechanism which is fix with the various size of the pipe while the upper part of the robot will be making the mechanism that can be provided the turning motion and steering motion. Doing some experiment to the previous in-pipe robot by changing the speed of the motor to make the robot turning (steering). After experiment, the in-pipe robot can turn to the right side by controlling the speed of the motor.

Besides that, the in-pipe robot fails to move in pipe when sometime test of the robot. Root cause of this problem was being the unstable screw mechanism. The front wheel was not stable when in the pipe. The spring constant, K in the upper part very high and made the motor need more torque to overcome the force of the spring to move upward.

After analysis the previous design, new design will draw using the SolidWorks. Fabrication the robot in the lab mechanical school. The robot will control using the Arduino programming while the Bluetooth use as the control system to control the robot motion. After completing the prototype robot, experimental will carry out to check that achieve the objective. The first step for fabrication will be finding the suitable wheel and design the holder based on the wheel.

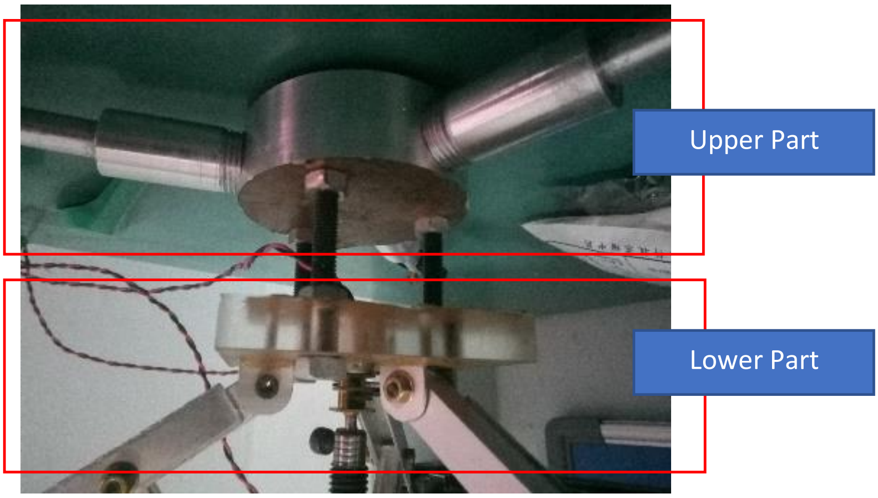


Figure 1.5 Shown that the prototype of the robot.

CHAPTER 2: LITERATURE REVIEW

2.1 Literature Review

In this chapter 2, will discusses the existing in-pipe robot that been researched. Type of in-pipe robot, the existing moving mechanism, and the mechanism that attract to the wall will also be discussing.

2.2 Type of In-Pipe Robot

There have many types of in-pipe robot was discovering to carry out the task such as inspect the crack, corrosion in pipe which this task was danger to human to carry. There have many years; the researcher was design the new in-pipe robot and some will try to redesign the existing in-pipe robot by using the new mechanism which not founded.

2.2.1 Pipe Inspection Gauges (PIG)

This type of in-pipe robots has the advantage of no need for actuator. It drives with the help of the force of fluid moving or the gas pressure moving. Disadvantage of this type of robot will difficultly control the speed of the robot and difficult to control direction when in the T-junction [12,13,14].

Figure 2.2.1 Pipe inspection gauges' type of in-pipe robot [12]

2.2.2 Wheeled In-Pipe Robot

Wheeled in-pipe robot are built with the simple design and able to steer but this type of the robot only can be using for pipes with a horizontal section. The robot does not have the support to the robot structure while moving inside the pipe unless there have more wheel track [12,13,14].

Figure 2.2.2 Wheeled in-pipe robot [12]

2.2.3 Caterpillar Type

The mechanism of caterpillar type almost same with the wheeled in-pipe robot, so that this type of robot will only work in the horizontal pipe. The design of the wheel will combine the front and the back side. This will be energy efficiency than the wheeled type robot. The robot can be design to varying diameter pipes [12,13,14].

Figure 2.2.3 Caterpillar type of in-pipe robot [12]

2.2.4 Wall- Pressing Type

This type of the in-pipe robot is useful not only in the horizontal pipe but also the vertical pipe. The robot contains flexible links that can be providing the sufficient amount of force to the wall and avoid the robot slippage in vertical pipe [12,13,14].

Figure 2.2.4 Wall-Pressing type of in-pipe robot [12]

2.2.5 Walking Type

Walking type of in-pipe robots are less using in the industry. This is because this type of the robot difficult to control due to too many actuators amounted on the robot. The robot design was complexity and needs the experience or training worker to control the robot [12,13,14].

Figure 2.2.5 Walking type of in-pipe robot [12]

2.2.6 Inchworm Type

Inchworm type in-pipe robot the movement of the robot will like the movement of inchworm which the front part will move first followed by the back part (expend and contract). This type preferred for the pipe with the small diameter because of the costing of build this robot. This type of robot will have low-speed mobility [12,13,14].

Figure 2.2.6 Inchworm type of in-pipe robot [12]

2.3 Existing Moving Mechanism

To make sure the in-pipe robot can move in the any type of the piping, the mechanism of moving was important to the robot. There has a little research on the moving mechanism for in-pipe robot to be as the reference.

2.3.1 Selective Drive Mechanism

With this mechanism, the motor will control the speed to make the robot turning. There have a few design on this direction of mechanism. Roh S.G, Do W.K, Jung-sub lee, Moon H.P, and Choi H.R have design the in-pipe robot based on selective drive mechanism.

A steering algorithm for branch-pipe driving adopts the same algorithm. When enter a branch pipe, all three clutches are operated to transmit power to the robot so that the robot can turn to a desired power. Making a speed of the motor of the driving units differently and to turn by controlling the wheel speed of each driving unit. This robot contains the three motors to drive. When the robot is travelling in the straight-pipe driving, speed of each driving unit is the same.

When the robot is travelling in the elbow, that will be shutting off the clutches of two driving units and keeping the wheels idles and running only one driving unit. When the robot is driving in branch, the two pipes robot enters a branch pipe, all three clutches are operated to transmit power to the robot, but the speed of the motor of the driving unit differently instant to make the robot turning. Disadvantage of this robot cannot connect wirelessly and this robot cannot move in to the various size of the piping [9,16].

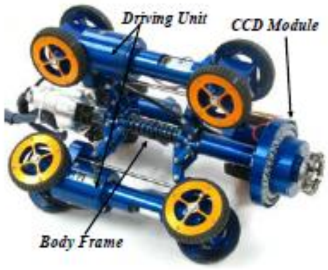


Figure 2.3.1 The prototype of the robot for selective drive mechanism [9]

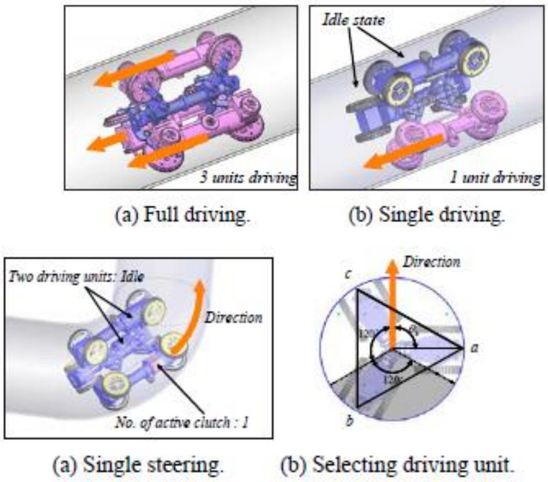


Figure 2.3.1 (a) The mechanism of the robot moving [9]

2.3.2 Screw Drive Mechanism (Moving in the Helical Motion)

Atsushi Kakogawa and Shugen Ma have the design the mobility of an in-pipe robot with this screw drive mechanism. Helical motion inside a straight pipe with the advantage of only one actuator is adopted to provide motion to the rotator mechanism and performs dexterous mobility in both straight pipes and curved pipes. The robot with the lightweight of 0.9kg and energy saving. Disadvantage of the robot are not traversable ability in the T-Shape of piping and limitation are cannot move in the different size of pipe [5,17].

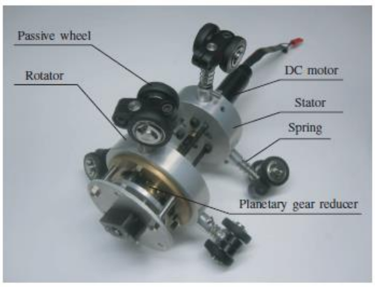


Figure 2.3.2 The prototype of the robot for screw drive mechanism [5]

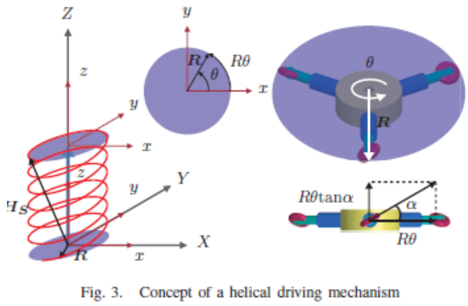


Figure 2.3.2(a) Mechanism for the robot moving in the straight pipe [5]

Besides that, there have another design also in the screw drive mechanism by Te Li, Shugen Ma, Bin Li, Wang M.H, Li Z.Q, and Wang Y.Q. The robot designed can move in curved pipes, vertical straight pipes and horizontal pipes. The front robot leg is design with slide angle, as the experiment is done the more the slide angle, the more the velocity of the robot move. While the disadvantage of this robot is cannot move in the T shape pipes and cannot control the direction. The robot using the screw drive mechanism, adaptive linkage mechanism, rotational elastic arms, and supporting elastic arm [7,18].

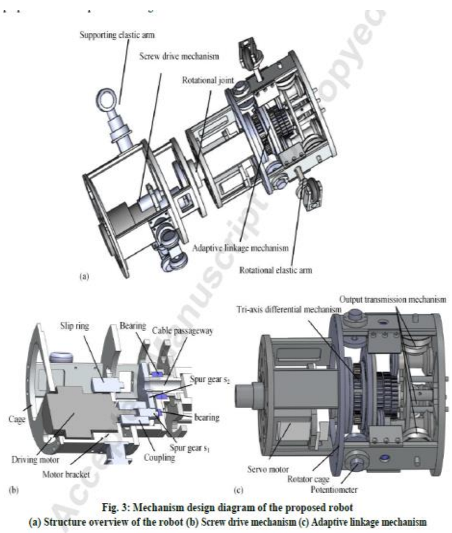


Figure 2.3.2(b) Prototype for the screw drive mechanism [7]

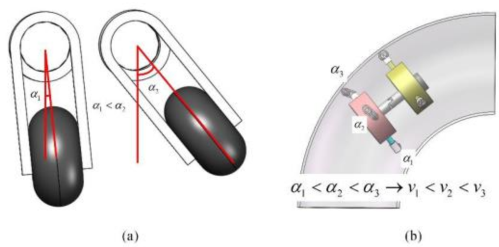


Figure 2.3.2(c) Mechanism for the robot wheel setup [7]

2.3.3 Two Wheel Chains Mechanism

The robot was design like the motorbike. The front wheel will control the direction of the robot to be moving while the back wheel will drive the motor to moving the front. Moving mechanism must combine with the linkages moving to stable the robot when inside the pipe.

Kwon Y.S, Bae Lee, In-Cheol Whang, Kim W.K and Yi B.J was design this type of moment mechanism. The robot designed fit into size of the pipes (80mm to 100 mm). This robot has the driving and steering capability with two-wheel chains. The robot can move in the "T-shape" pipe by controlling the front chain. The robot has three motors in the robot which one motors is for the steering purpose, another one for the driving purpose and one motor making the robot attract to the wall. Disadvantage of this robot was not stable when moving in the pipe and cannot control the wirelessly [1,2].

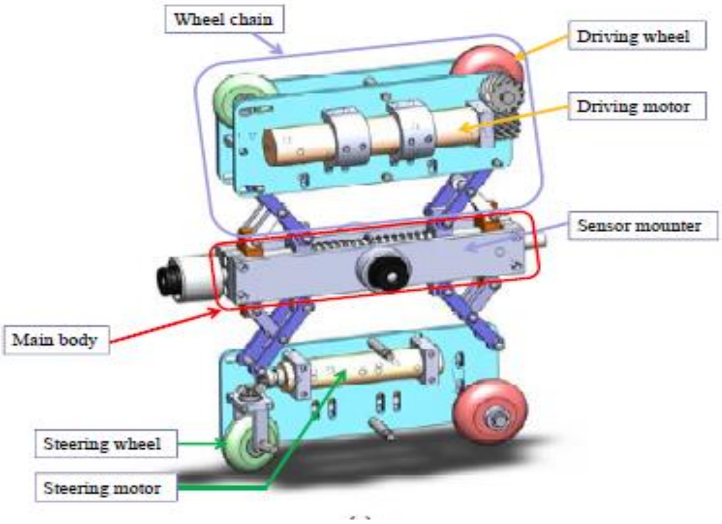
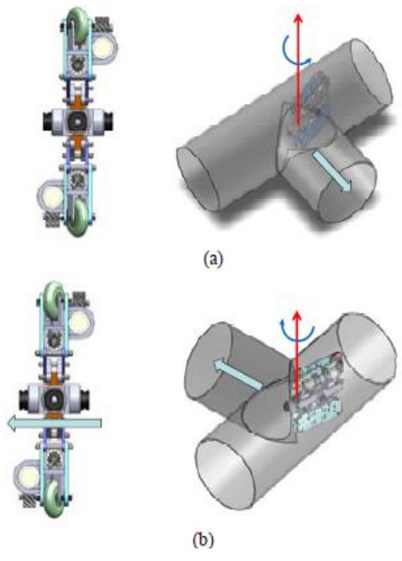


Figure 2.3.3 The prototype of in-pipe robot [1]



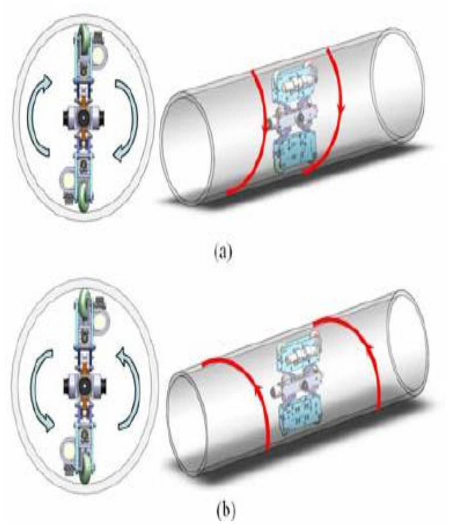


Figure 2.3.3(a) The mechanism for the in-pipe robot moving in the pipe [1]

2.3.4 Gear Mechanism

The moving of in-pipe robot will be moving and making turning using the gear mechanism. This mechanism was reducing the cost and power consumption for a motor.

This new mechanism was designed by the Taikiki Nishimura, Atsushi Kakogawa and Shugen Ma. The robot designed with the 2 motors which is the driving motor and steering motor which can be select pathways of movement. They got three locomotion modes which are the screw driving (move forward and backward), steering (T-branches or elbow pipes), and rolling modes (change the direction of navigation in pipes when it cannot steer). Screw driving mode power by the driving motor to move forward and backward. Steering mode power by the steering motor to move in the T-branches/elbow pipes. Rolling mode is to change the direction of navigation in pipe when it cannot be steered. The spiral mitre gears are using in the steering mode while using the pinion gear in the rolling mode. This mechanism able the robot to navigate through the T-branch using only two actuators. The disadvantages this mechanism no stable when moving and the pathway selection still not efficiency [8].

Figure 2.3.4 The prototype of the in-pipe robot [8]

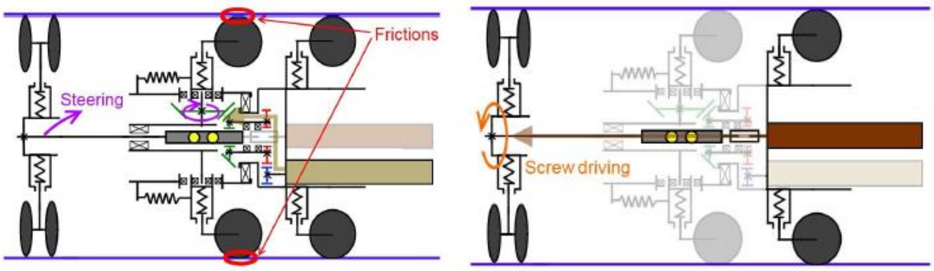


Figure 2.3.4(a) Mechanism for in-pipe robot to move forward and turning [8]

2.4 Existing Mechanism for In-Pipe Robot Attract in The Pipe

To make sure the in-pipe robot will be move stability in the pipe, the mechanism to attach the pipe is very important.

2.4.1 Wall-Pressed Wheel Type of In-Pipe Robot

In order to stability the robot in pipe, the robot will extend linkages to pressure to the wall. This type mechanism will provide the food traction force for the robot to move forward and backward.

There have a few pervious design on this type. Kwon Y.S, Bae Lee, In-Cheol Whang, Yi B.J was design this type of the robot. The dimension of the robot; length of a robot 80mm and the exterior diameter of the robot body changes form 90mm up to 110mm. Type of mechanism using is linkage-type mechanical clutch. The robot contains of two modes which are the driving mode and retrieval mode. Disadvantage of this robot cannot navigation the direction of turning and the robot cannot communication wirelessly [3].

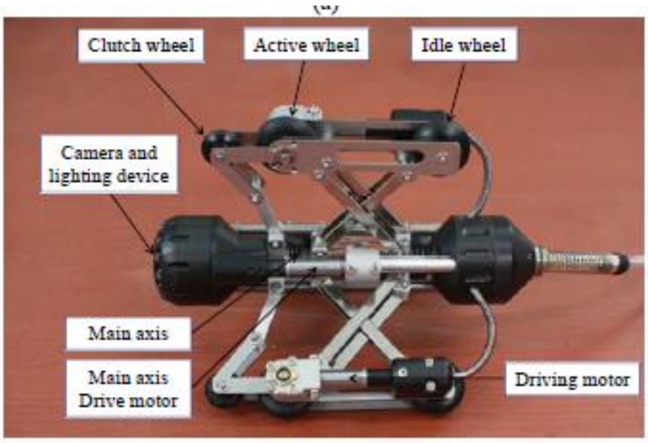


Figure 2.4.1 The prototype of in-pipe robot [3]

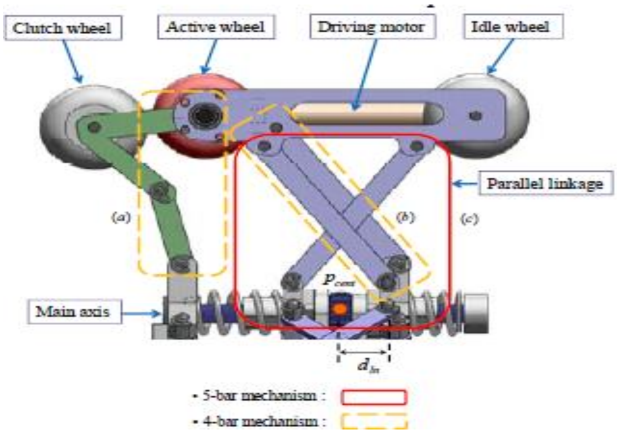


Figure 2.4.1.1 The mechanism of the in-pipe robot to extend the linkage [3]

2.4.2 Wheeled Wall- Pressed Type (Pneumatic Pressure)

This type of the robot will be using the pneumatic pressure to make the robot stuck on the pipe to stability the robot. Chang Doo Jung, Won Jee Chung, Jin Su Ahn, and Myung Sik Kim was design the in-pipe cleaning robot with can be change the size of the robot using the pneumatic pressure. The robot is designed to fit into two types of pipe (300mm or 400mm in diameter). And the robot is adjusted fit into the inner face of a pipe using the pneumatic pressure (Not Spring). The body of the robot are not feasible and not applicable in the bending type of pipe [6].

Figure 2.4.2 The prototype of in-pipe cleaning robot including 6-link sliding mechanism with optimal dimension [6]

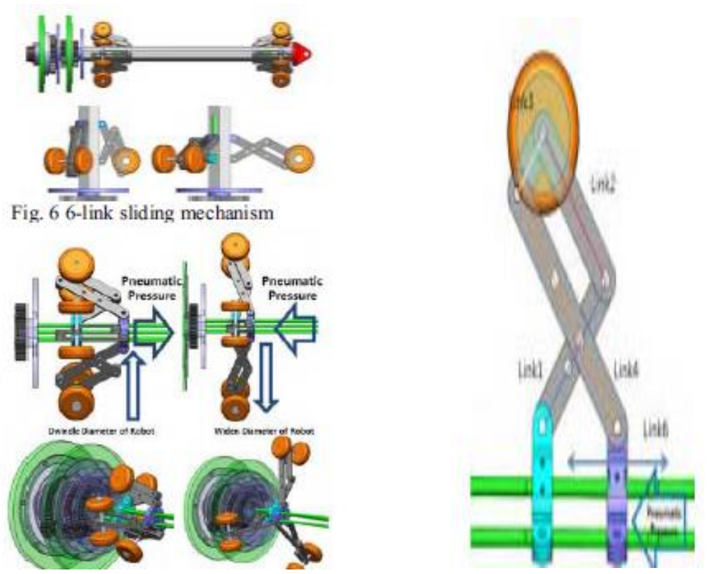


Figure 2.4.2.1 The mechanism for the in-pipe robot extend and contract [6]

2.4.3 Spring Mechanism

Using the force of spring to pressure to the wall, to make the robot stability when moving in the pipe. There has the study on this spring constant to make the robot more stable in-pipe.

Atsushi Kakogawa and Shugen Ma was study on stiffness design of springs for a screw drive in-pipe robot to pass through curved pipes and vertical straight pipe. This journal is study about the mobility of the robot changes depending on the spring stiffness and the motor torque. And the conclusion of this study, when the spring stiffness is high, the robot can pass through horizontal and vertical straight pipe. When the spring stiffness is low, the robot can pass through a horizontal straight pipe, but not a vertical one because of slippage without enough propulsion [4].

CHAPTER 3: METHODOLOGY

3.1 Case Study On Existing Robot

In the past years, there have a few in-pipe robot was study, design and prototype out. There have a few types of the robot there are found on the internet which is the wheeled robot, inchworm robot, snake robot, robot with a linkage type mechanical clutch, spring-loaded robot, and pipe crawling robot. Each type of the robot was design to help the human on the complex, danger work.

Wheel robot is more widely using due to the simple mechanism and design. Using the differential driving due to its ability in branches navigation. Next, inchworm robot and snake robot was design with the many degrees of freedom, which permit a wide range of different motion. This type of the robot will need the higher power consumption to move the robot.

Screw drive in-pipe robot has advantages of low power consumption with using the motor only. Disadvantage of this kind of robot will difficultly maintain its posture while steering the front unit and the robot make will only fix in to one diameter of piping only. Screw mechanism using to extend and release the leg to fix the piping not sufficient due to power consumption.

When in-pipe robot was design, there have a few considerations need to be considering such as the power consumption, pass through the various size of piping, and moving in the T-branches of piping. Therefore, the design of the robot will be using the concept of compression force stored in the spring attached between the parts. This will reduce the number of actuator and less energy consumed.

3.2 Project Methodology Flow

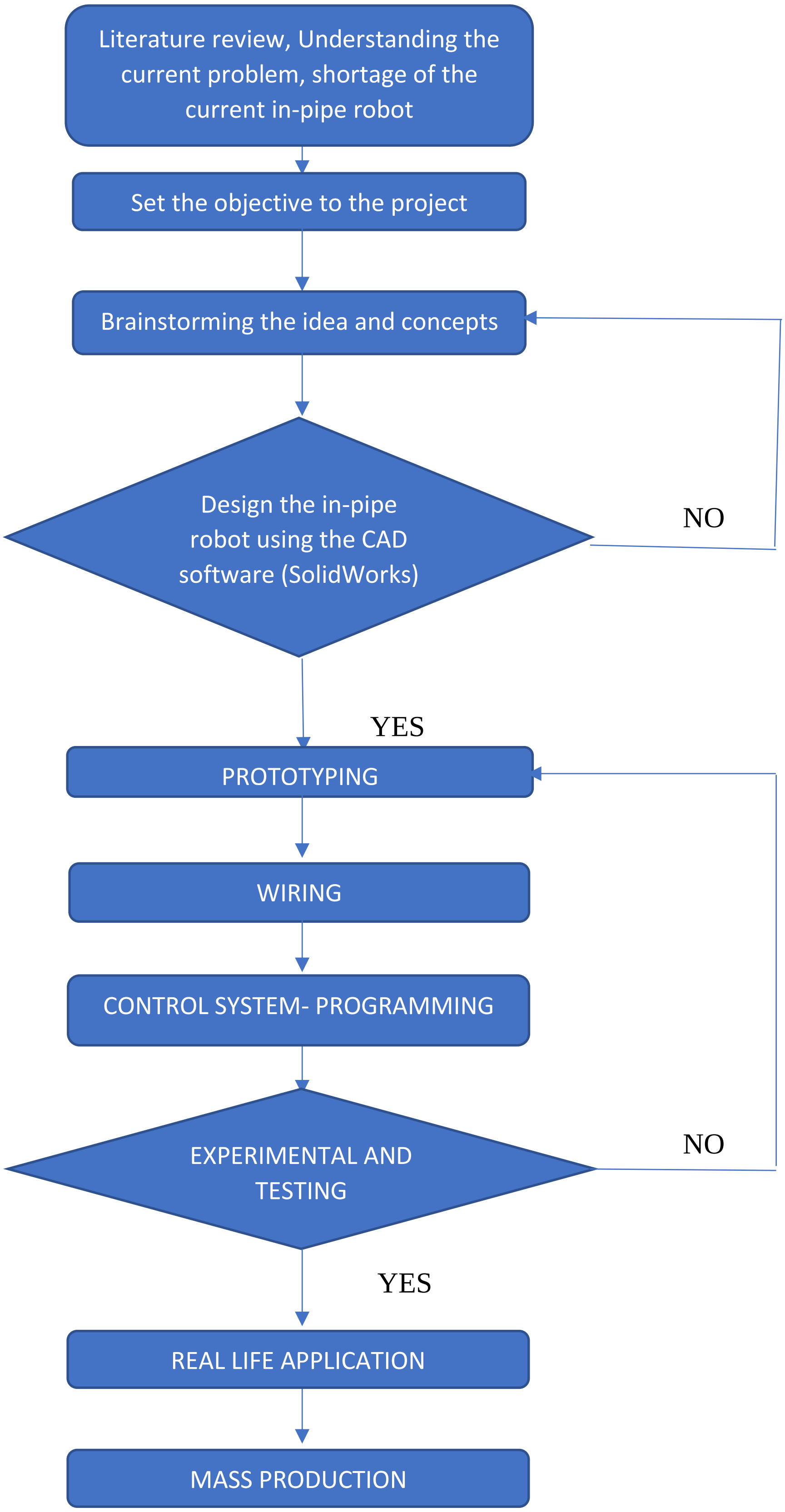


Figure 3.2 The project flow chart

3.3 Design of the Solid Model Using CAD Software

After understanding the current situation, brainstorming the ideal and concept of design the mechanism for the robot to turning. After a few times of generating the ideal, the ball joint and ball wheel was finalized. Every part of 3D model was sketched using the CAD software (SolidWorks). All part was assembly using the assembly function to from the 3D model that shown in the figure [15].

3.3.1 SolidWorks Modelling

Figure above shown that full design of the in-pipe robot using the software SolidWorks. The in-pipe robot can separate into two parts which is the upper part and the lower part. The two parts are jointing using the ball joint to make the upper part flexible to move right and left. The front wheel consists of three passive wheels while the lower part consists of three active wheels which will attract with the DC 6V gear metal motor. All the wheel was design to make it flexible, the spring are added inside. This is because to make the wheel can be extending or release. Control system device such as Arduino Uno, Bluetooth, and L293D motor shelf drive will put in the box at the middle box. To make the wheel stable when moving in the pipe, the design will make in the square shape intend of using the circular shape. Exploded view for in-pipe robot design shown in the Appendix C.

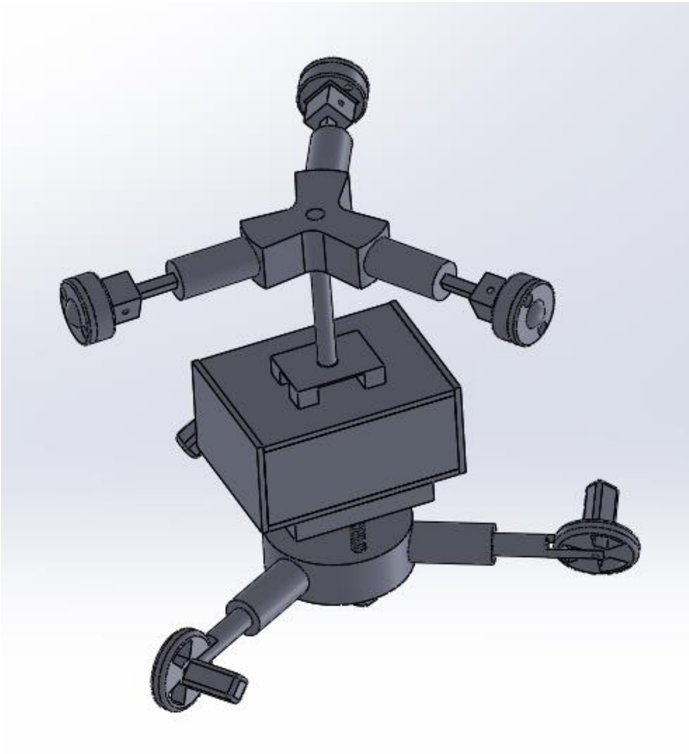


Figure 3.3.1 Overview of the In-pipe robot

3.3.2 Locomotion and Moving Mechanism

The three motors allocated in the back side of the robot. Each of the motor separate with the angle of 120 degrees. The robot was design with two modes of locomotion which is the driving and steering. The robot was able to navigate through T-branches pipe. For the motor, we defined in the programming when the motor rotates in the clockwise direction that mean the robot moving in the forward direction while the motor rotate in the anticlockwise direction that mean the robot moving in backward direction.

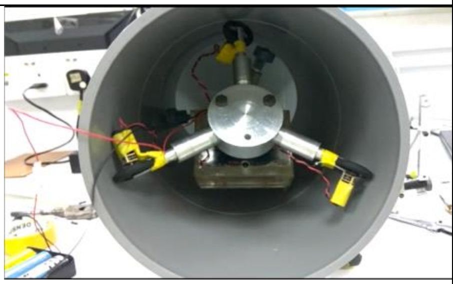
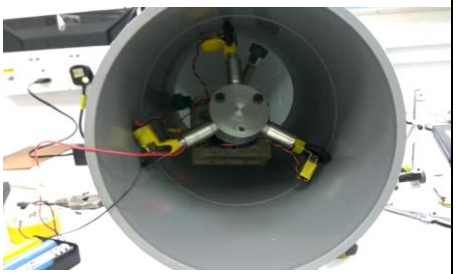
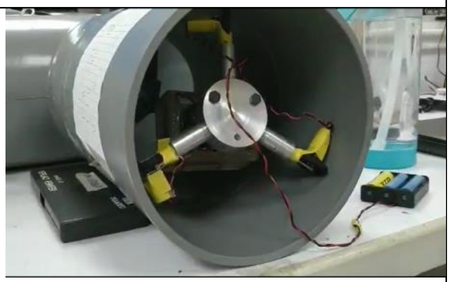
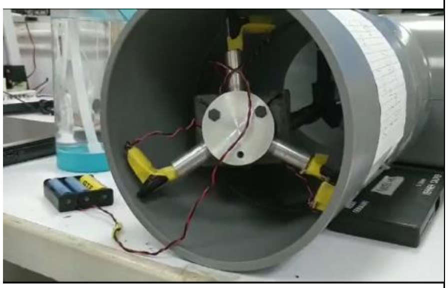
3.3.2.1 Driving Mode

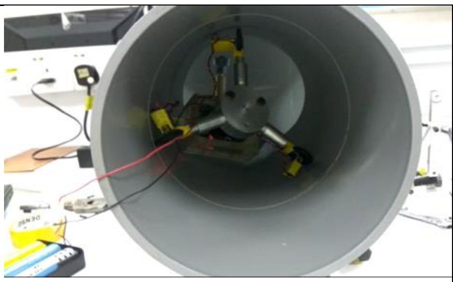
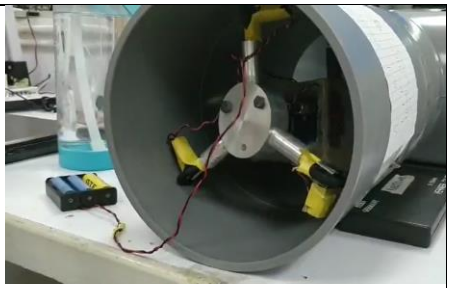
In this driving mode, the robot can move forward and backward. All the three motor will be moving with the maximum speed with the clockwise direction for driving forward direction while when three of the motor rotate with the maximum speed with the anticlockwise direction the robot will move backward.

3.3.2.2 Steering Mode

In this steering mode, the robot can move in the T-branch piping that have a small radius of curvature. There have the two difference types of turning the robot which will show in the table below.

Table 3.3.2 The two difference method of steering mode

One of the motor will reduce the speed compared to another one.	Two motor will rotator in the difference direction.
1.  2. 	1.  2. 

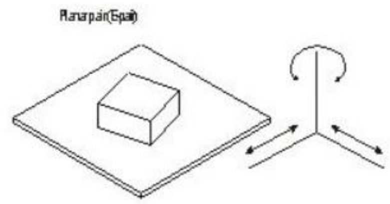
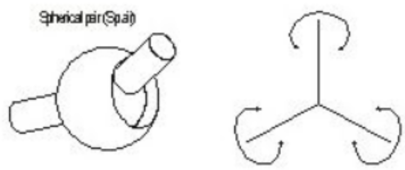
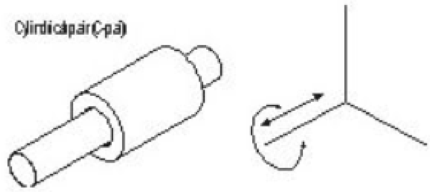
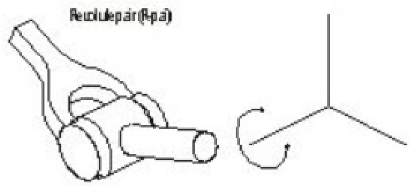
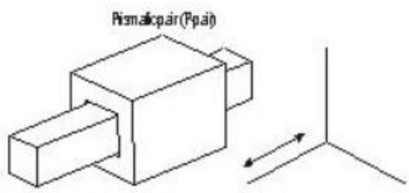
3. 	3. 
For this case, the one of the motor will set the speed by half to another motor. So that, the motor will making the turning to side that the low motor speed.	For this case the two motor on the bottom side will set rotation in the opposite direction. So that, the robot can turn the front part to that direction.

3.3.3 Kinematic Joint

In my design of in-pipe robot, it separates into two parts. In order to joint two part together, the ball joint (kinematic joint) is using. Kinematic joints are most important part of a mechanism. The kinematic joints will allow motion in some directions and constrains it in other. The types of motion and constrained are depended on the degree of freedom of a joint. Kinematic joint can be classified into two types which is the lower pair joint and higher pair joint. The difference between this two is a higher pair joint is one which contact occurs only at isolated points or along a line segment while the lower pair joint can contact two rigid bodies occur at every point. There has the few kinematic joints has been shown in the Table 3.3.3.

After making the decision, the spherical joint was decided using to join the two parts of the body. The ball joint is allowing free rotation in two planes at the same time while preventing translation in any direction which is fully meet requirement of the making this robot. Besides that, in my design of the robot the translation is not required. As the Table 3.3.3 shown that left only the spherical joint and the revolute joint. Finally, the spherical joint is using because the rotation is more that the revolute joint which can make the robot can be turned in the more direction.

Table 3.3.3 Shown that the all kinematic joint

Kinematic Joint	Relative Motion	Degree of freedom	Schematic Diagram and Sketch Symbol
Planner Joint	1 rotation 2 translation	3	
Spherical Joint	3 Rotation 0 translation	2	
Cylindrical Joint	1 rotation 1 translation	2	
Revolute Joint	1 rotation 0 translation	1	
Prismatic Joint	0 rotation 1 translation	1	
Helical Joint	1 rotation 1 translation	1	

3.4 Spring and Motor Calculation

On this section, the force of the motor was calculated. It is to make sure that the robot can support the weight of the robot to make the robot can move front and upward.

3.4.1 Force Motor Calculation

In this design, the motor will direction touch the wall, the free body diagram of the whole robot will show in the Figure 3.4.1.

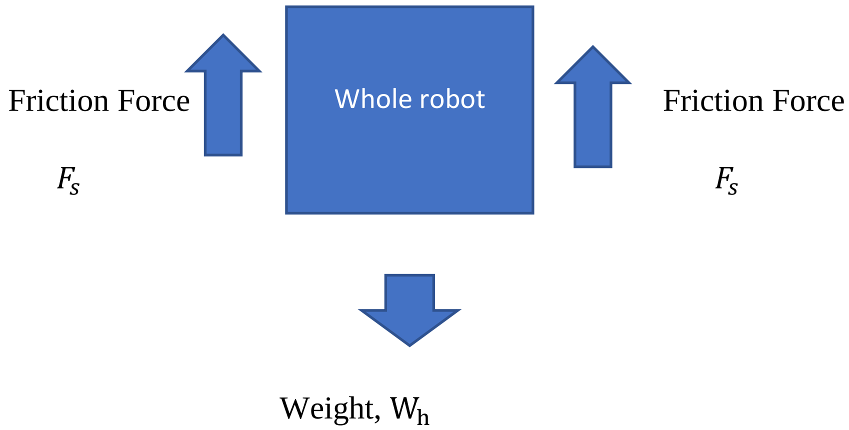


Figure 3.4.1 Free body diagram of the whole robot (Y-axis).

The robot will have three wheels that will be touch the wall and give the three friction force. Therefore, in theoretically there will be had the three friction force. From the Figure 3.4.1, the static equation will be shown as follows

$$\text{Weight, } W_h = 3 \text{ Friction Force } ,F_s \ldots\ldots\ldots\ldots(1)$$

Weight of the robot, W_h as shown in the figure 3.4.2 is 0.8kg which is 0.8×9.81 =7.848N. Therefore, form the equation one, each of the wheel have the friction force, F_s equal to the 2.616N .

Figure 3.4.2 Weight of the robot

The forward force required is $F = ma$ which m=is the mass of the robot and a =acceleration of the robot. Assuming the robot need to accelerated at the 2.0m/s/s. Therefore, the forward force is equal to 1.6 N. To find the required torque on the wheel's axial, using the equation below:

$$Torque\ ,\tau = Wheel\ Radius, r\ \times force$$

$$Torque\ ,\tau = 0.0185m\ \times 1.6\ N$$

$$Torque\ ,\tau = 0.0296\ \text{N.m}$$

3.4.2 Spring Calculation

The robot will have three wheels that will be touch the wall and give the three spring force. The maximum length of the spring, x = 40mm = 0.04m. From the Figure 3.4.3, the normal force, F_c will equal to the spring force , F_s as shown as formula below:

$$F_c = 3F_s$$

$$m \times g\ = 3 \times k \times x$$

$$0.8kg\ \times 9.81\frac{m}{s^2} = 3 \times k \times 0.04m$$

$$k = 65.4\ N/m$$