

**DESIGN AND DEVELOPMENT OF COOPERATIVE  
CONTROLLED TWO ROBOTS FOR PIPELINE INSPECTION**

**LAW KOK WAH**

**BACHELOR OF MECHATRONICS ENGINEERING WITH  
HONOURS  
UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2019**

**DESIGN AND DEVELOPMENT OF COOPERATIVE CONTROLLED TWO  
ROBOTS FOR PIPELINE INSPECTION**

**LAW KOK WAH**

**A report submitted  
in partial fulfillment of the requirements for the degree of  
Bachelor of Mechatronics Engineering with Honours**

**Faculty of Electrical Engineering**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2019**

## DECLARATION

I declare that this thesis entitled “Design And Development of Cooperative Controlled Two Robots For Pipeline Inspection” 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 : LAW KOK WAH

Date : 19 June 2019

## **APPROVAL**

I hereby declare that I have checked this report entitled “Design And Development of Cooperative Controlled Two Robots For Pipeline Inspection” 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 appreciation and deepest gratitude to the people who have helped and supported me throughout my final year project. My final year project would not have been possible without the contribution and collaboration of others. A special thanks to my supervisor, Assoc Prof. Dr. Mohd Shahrieel bin Mohd Aras for his support and constant supervision which contributed immensely to my personal development. I also want to thank him for gave me a lot of valuable advices and guidance at every stage of my project progress in this whole semester.

Besides, I would like to thank the panels and the rest of lecturers for their guidance and advices which helped me a lot to overcome the challenges that I faced during my final year project.

Last but not least, I would like to place on record my grateful appreciation to all my friends and family for sharing their experiences, time and commitment during my final year project. I am grateful because I have a lot of friends who were always there for me to help and support me during my entire final year project.

## ABSTRACT

Pipeline explosion is the most dreadful incident in the oil and gas industry which cause a huge number of fatality and financial loss every year. The existing pipeline inspection robots is costly and the efficiency and flexibility of the single robot system is low in case the pipeline have 2 ways such as T-branch. Therefore, the affordable cooperative controlled two robots for pipeline inspection are developed where the robots are applicable for the horizontal pipeline which used to transport air or gas. This project also aims to evaluate the performance of the developed mobile robots and develop the communication between the mobile robots. A simple structure wheeled type robot has good performance in T-branch accessibility is stated. Besides, Bluetooth module is the most common tools to develop the communication between the multi robot system due to its ease to use and can communicate with other Bluetooth enabled devices. Few experiments such as performance of mobile robot on various type of surfaces, tracking object using ultrasonic sensor, leader-follower approach and tracking control of mobile robot are designed to evaluate the performance and communication between the mobile robots. A PVC pipe with T-branch is built to verify the mobile robots in T-branch accessibility. Through the experiment, the mobile robot is successfully pass through the pipeline with various type of surfaces. The speed, efficiency and accuracy are also evaluated through the experiment. The master and slave robot are able to perform forward, backward, turning left and right movement without having communication loss or disconnected in the PVC pipe.

## ***ABSTRAK***

Letupan saluran paip adalah kejadian paling mengerikan dalam industri minyak dan gas yang menyebabkan banyak kematian dan kerugian kewangan setiap tahun. Robot pemeriksaan saluran paip yang sedia ada di pasaran adalah mahal dan kecekapan serta fleksibiliti sistem robot tunggal adalah rendah sekiranya saluran paip mempunyai 2 arah seperti T-cawangan. Oleh itu, dua robot yang dikawal dengan kooperatif dan harga berpatutan untuk pemeriksaan saluran paip dicadangkan di mana robot itu boleh digunakan untuk saluran paip mendatar yang digunakan untuk mengangkut udara atau gas. Projek ini juga bertujuan untuk menilai prestasi robot mudah alih yang dibina dan membangunkan komunikasi antara robot mudah alih. Robot jenis beroda mempunyai prestasi yang baik dalam akses T-cawangan dipilih. Selain itu, modul Bluetooth adalah alat yang paling biasa untuk membangunkan komunikasi di antara sistem multi robot kerana ia mudah digunakan dan boleh berkomunikasi dengan peranti berkemampuan Bluetooth yang lain. Beberapa eksperimen seperti prestasi robot bergerak pada pelbagai jenis permukaan, objek penjejakan menggunakan pengesan ultrasonik, pendekatan pemimpin-pengikut dan kawalan penjejakan robot bergerak telah direka untuk menilai prestasi dan komunikasi antara robot mudah alih. Paip PVC dengan T-cawangan telah dibina untuk mengesahkan robot mudah alih dalam pengaksesan T-cawangan. Melalui eksperimen, robot mudah alih berjaya melalui saluran paip dengan pelbagai jenis permukaan. Prestasi seperti kelajuan, kecekapan dan ketepatan juga telah dinilai melalui eksperimen. Robot pemimpin dan pengikut dapat melakukan gerakan ke depan, ke belakang, mengubah gerakan kiri dan kanan tanpa kehilangan komunikasi atau terputus di dalam paip PVC.



## TABLE OF CONTENTS

	<b>PAGE</b>
<b>DECLARATION</b>	
<b>APPROVAL</b>	
<b>DEDICATIONS</b>	
<b>ACKNOWLEDGEMENTS</b>	<b>iv</b>
<b>ABSTRACT</b>	<b>v</b>
<b>ABSTRAK</b>	<b>vi</b>
<b>TABLE OF CONTENTS</b>	<b>vii</b>
<b>LIST OF TABLES</b>	<b>x</b>
<b>LIST OF FIGURES</b>	<b>xi</b>
<b>LIST OF SYMBOLS AND ABBREVIATIONS</b>	<b>xiv</b>
<b>LIST OF APPENDICES</b>	<b>xv</b>
<b>CHAPTER 1 INTRODUCTION</b>	<b>1</b>
1.1 Introduction	1
1.2 Motivation	2
1.3 Problem Statement	4
1.4 Objectives	5
1.5 Scope	5
1.6 Summary	6
<b>CHAPTER 2 LITERATURE REVIEW</b>	<b>7</b>
2.1 Introduction	7
2.2 Cooperative Controlled Robots	7
2.3 Communication in Multi Robot System	9
2.4 Pipeline Inspection	11
2.5 Pipeline Inspection Robot	14
2.5.1 Wheel Type Robot	14
2.5.2 Caterpillar Type Robot	16
2.5.3 Non-wheel Type Robot	18
2.6 Table Comparison of Cooperative Controlled Robots	20
2.7 Table Comparison of In-pipe Inspection robot (IPIR)	22
2.8 Critical Literature Review	24
2.9 Summary	25

<b>CHAPTER 3</b>	<b>METHODOLOGY</b>	<b>26</b>
3.1	Introduction	26
3.2	Overall Process Chart of Project	26
3.3	Cooperative Controlled Robots Design	27
3.4	Hardware Development	28
3.4.1	Controller	29
3.4.1.1	Arduino Uno	29
3.4.1.2	L298P Motor Shield	30
3.4.2	Communication	30
3.4.2.1	Bluetooth Module	30
3.4.3	Sensory System	31
3.4.3.1	Ultrasonic Sensor	31
3.4.3.2	Infrared Sensor	32
3.4.4	Monitoring	33
3.4.4.1	Mini WIFI Camera	33
3.4.5	Motion	33
3.4.5.1	DC Gear Motor	33
3.4.5.2	Servo motor	34
3.4.6	Power Management	35
3.4.6.1	Lithium Battery	35
3.5	Program Development	36
3.5.1	Arduino IDE	36
3.6	Design and Assembly of Master-Slave Robot	37
3.7	Flowchart of the Cooperative Controlled Robot System	41
3.8	Experiment Setup	43
3.8.1	Experiment 1: Performance of mobile robot in pipeline	44
3.8.2	Experiment 2: Tracking object using ultrasonic sensor	47
3.8.3	Experiment 3: Leader-Follower approach	49
3.8.4	Experiment 4: Performance of the master and slave robot in various type of trajectories	53
3.9	Summary	54
<b>CHAPTER 4</b>	<b>RESULTS AND DISCUSSIONS</b>	<b>55</b>
4.1	Introduction	55
4.2	Experiment 1: Performance of mobile robot on various type of surfaces	55
4.3	Experiment 2: Tracking object using ultrasonic sensor	57
4.4	Experiment 3: Leader-Follower approach	60
4.5	Experiment 4: Performance of the master and slave robot in various type of trajectories	63
4.5.1	Straight Line Trajectory	64
4.5.2	Straight Line Trajectory with Obstacle	66
4.5.3	U-shape Trajectory	69
4.5.4	U-shape Trajectory with Obstacle	71
4.5.5	S-shape Trajectory	73
4.5.6	S-shape Trajectory with Obstacle	75
4.6	Demonstration of the movement of master and slave robot in the pipeline	77
4.6.1	Case 1: Without obstacle	77

4.6.2	Case 2: With obstacle at the first branch	79
4.6.3	Case 3: With obstacle at the second branch	81
4.7	Summary	83
<b>CHAPTER 5</b>	<b>CONCLUSION AND RECOMMENDATIONS</b>	<b>84</b>
5.1	Conclusion	84
5.2	Future Works	85
<b>REFERENCES</b>		<b>86</b>
<b>APPENDICES</b>		<b>90</b>

## LIST OF TABLES

Table 1.1: Total number of IPE case by cause (2013-2017)	2
Table 2.1: Description of application of MRS [7]	8
Table 2.2: Advantages and disadvantages of both communication mechanism [10]	10
Table 2.3: Factors that affect the communication in MRS [10]	10
Table 2.4: Classification of in-pipe inspection robot [18]	14
Table 2.5: Comparison of cooperative controlled robots from previous studied journals and papers	20
Table 2.6: Comparison of in-pipe inspection robot from previous studied journals and papers	22
Table 3.1: Specification of Arduino Uno [32]	29
Table 3.2: Pin configuration connection between the electrical components and shield.	40
Table 3.3: Mapping of experiments and objectives	43
Table 4.1: Observation results of the performance of mobile robot on various type of surfaces	56
Table 4.2: Effective angles of ultrasonic sensor	58
Table 4.3: Data collected for master and slave robot over time	61
Table 4.4: Summarize data of root mean square error for all the trajectories	63

## LIST OF FIGURES

Figure 2.1: Pigs device that used in intelligent pigging method [14]	12
Figure 2.2: Wheel type robot with simple structure	15
Figure 2.3: Wheeled wall pressed robot with four wheel chain [17]	15
Figure 2.4: Wheeled wall pressed robot with screw type robot [17]	16
Figure 2.5: Caterpillar type robot with simple structure	17
Figure 2.6: Structure of caterpillar wall pressed type robot [17]	17
Figure 2.7: Simulation of walking type robot with two set of four legs [19]	18
Figure 2.8: Structure of inchworm type robot [20]	19
Figure 2.9: Structure of snake type robot [19]	19
Figure 3.1: Overall progress chart of the project	27
Figure 3.2: Illustration of the cooperative controlled robot system	28
Figure 3.3: L298P Motor Shield	30
Figure 3.4: Bluetooth module HC-05	31
Figure 3.5: Ultrasonic sensor	32
Figure 3.6: Infrared sensor	32
Figure 3.7: Mini WIFI Camera	33
Figure 3.8: DC Gear Motor	34
Figure 3.9: Tower Pro SG90 Servo Motor	34
Figure 3.10: Lithium ion BRC 18650 Battery	35
Figure 3.11: Arduino IDE Programming Software	36
Figure 3.12: Aluminum Chassis	37
Figure 3.13: Top view of mobile robot	38

Figure 3.14: Front view of mobile robot	38
Figure 3.15: Side view of mobile robot	39
Figure 3.16: Back view of mobile robot	39
Figure 3.17: Flowchart of the cooperative controlled robots system	42
Figure 3.18: Various type of surfaces	45
Figure 3.19: Normal condition of pipe	46
Figure 3.20: Set up of pipe with small stones	46
Figure 3.21: Set up of pipe with sand	46
Figure 3.22: Set up of pipe with soil	46
Figure 3.23: Set up of pipe with oil	46
Figure 3.24: Obstacle 10cm far from the ultrasonic sensor	48
Figure 3.25: Obstacle 20cm far from the ultrasonic sensor	48
Figure 3.26: Obstacle 30cm far from the ultrasonic sensor	48
Figure 3.27: Obstacle 40cm far from the ultrasonic sensor	48
Figure 3.28: Master Bluetooth module setup	50
Figure 3.29: Setting in AT command of master Bluetooth module	50
Figure 3.30: Slave Bluetooth module setup	51
Figure 3.31: Setting in AT command of slave Bluetooth module	51
Figure 3.32: Same startup point of master and slave robot	52
Figure 4.1: Time taken of mobile robot in travelling various type of surfaces	56
Figure 4.2: Graph of angle against average distance from ultrasonic sensor	59
Figure 4.3: Average distance travelled by master and slave robot over time	61
Figure 4.4: Speed of master and slave robot over time	62
Figure 4.5: Trajectory in straight line	64

Figure 4.6: General view of graphical form of trajectory in straight line	65
Figure 4.7: Zoom in view of graphical form in straight line trajectory	65
Figure 4.8: Trajectory in straight line with obstacle	67
Figure 4.9: General view of graphical form of trajectory in straight line with obstacle	67
Figure 4.10: Zoom in view of graphical form of trajectory in straight line with obstacle	68
Figure 4.11: Trajectory in U-shape	69
Figure 4.12: Graphical form of trajectory in U-shape	70
Figure 4.13: Trajectory in U-shape with obstacle	71
Figure 4.14: Graphical form of trajectory in U-shape with obstacle	72
Figure 4.15: Trajectory in S-shape	73
Figure 4.16: Graphical form of trajectory in S-shape	74
Figure 4.17: Trajectory in S-shape with obstacle	75
Figure 4.18: Graphical form of trajectory in S-shape with obstacle	76
Figure 4.19: Demonstration of the master and slave robot in the pipeline without obstacle	78
Figure 4.20: Demonstration of the master and slave robot in the pipeline with obstacle at the first branch	80
Figure 4.21: Demonstration of the master and slave robot in the pipeline with obstacle at the second branch	82

## LIST OF SYMBOLS AND ABBREVIATIONS

IPE	-	Impacting people and environment
AI	-	Artificial Intelligent
MRS	-	Multi Robot System
USV	-	Unmanned Surface Vehicle
UAV	-	Unmanned Aerial Vehicle
HRI	-	Human Robot Interaction
ILI	-	In-line Inspection
MFL	-	Magnetic Flux Leakage
PIR	-	Pipeline Inspection Robot
CCD	-	Charge Coupled Device
CMOS	-	Complementary Metal Oxide Semiconductor
DC	-	Direct Current
IDE	-	Integrated Development Environment
Mbps	-	Megabytes per second
RPM	-	Rotations per minute
PVC	-	Polyvinylchloride
RC	-	Remote control
RMSE	-	Root Mean Square Error
AT	-	Attention Command
PWM	-	Pulse Width Modulation



## LIST OF APPENDICES

APPENDIX A	GANTT CHART	90
APPENDIX B	STRAIGHT LINE TRAJECTORY	91

# CHAPTER 1

## INTRODUCTION

### 1.1 Introduction

Mobile robot is an integration of different type of physical and computational components which are controlled automatically to solve the task given by human being. Basically, the mobile robots are designed and used in three major type of environment which are air, land and underwater. Mobile robots are widely used in industrial plant to solve the task which can't be solve by human being. Normally, the tasks are dangerous work and the environment is inaccessible by human being.

Pipeline inspection is one of the dangerous work that can be solved by the mobile robots. The purpose of pipeline is used for the movement in transporting the liquids and gases from one place to another place. Basically, the pipeline is used to transport the natural gas, fuel oils and drinkable water. The transporting activities are carry out every day. After a period of time, the pipes are exposed to the chance of break, leak or crack due to the rusting, pressure and aging [1]. These defects can cause the time to complete the transportation become longer. As a result, the business activities of the company will be effected and decelerate and it is a serious impact to the oil and gas industry. This is the main reason that pipeline inspection needed to carry out frequently to reduce the chance of incidents happen.

## 1.2 Motivation

The serious pipeline incident such as pipeline explosion which will cause fatality or injury due to corrosion failure, equipment failure, incorrect operation, material pipe failure and others incident causes [2]. In recent years, the case of pipeline incidents has been decreased due to the latest technology of pipeline inspection. However there are some case of pipeline incidents happen due to the weakness of the technology. Pipeline incidents cause destruction in terms of economy and fatality. Table 1.1 shows the total number of pipeline incidents that impact the people and environment (IPE) that occur in worldwide from 2013 to 2017 [2].

Table 1.1: Total number of IPE case by cause (2013-2017)

<b>Total IPE incidents by cause (2013-2017)</b>	
<b>Factor</b>	<b>Total Case</b>
Corrosion Defeat	168
Equipment Defeat	105
Material Pipe/ Weld Defeat	61
Mistaken Operations	60
Excavation incidents	47
Natural Force incidents	30
Other Causes	26
Outside Force incidents	23
<b>Total</b>	<b>520</b>

Based on Table 1.1, there are total 520 cases of IPE incidents that happen in the world. In other words, it is almost 100 cases of IPE incidents are happen every year. Main causes of the IPE incidents are corrosion and equipment failures.

Recently, a natural gas pipeline explosion has been happened in southeast New Mexico at 20 August 2018. The explosion has caused fatality which five adults and five children are killed in the incidents [3]. Besides, the explosion also caused two people in critical injury. The 30 inch pipeline exploded and left a crater about 86 feet long, 46 feet

wide and 20 feet deep [3]. The investigator of the incidents said that the explosion could have been happened because of some leakage of the pipeline and ignited by anything.

In terms of percentage of occurs, Malaysia is considered as a country with low percentage of pipeline incidents occurred. However, this should not be ignored because there is a pipeline incident that has been happened in Miri Sarawak at 11 Jun 2014. A pipeline explosion ripped apart a section of the Sabah-Sarawak interstate gas pipeline located in between Lawas town and Long Sukang in the northernmost district of Sarawak [4]. Although there are no fatality in the incident, but the incident causes a temporary business activity shut down. A RM4 billion project that owned by Petronas is shut down for a period of time [4]. The investigator of the incidents said that there must be some serious faults to have ignited the explosion.

In conclusion, an efficient mobile robots is needed in the field of pipeline inspection due to pipeline incidents bring a big impact to human being and environment. Although occurrence of pipeline incidents in Malaysia is less than other countries, however Malaysia should have an effective pipeline inspection robot to reduce or avoid the chance of pipeline incidents happening.

### 1.3 Problem Statement

The current technology for pipeline inspection robot is very advanced. With this current technology, many pipeline explosion incident can be avoid. The pipeline inspection robot that developed by the JETTY Robot company can even maintenance or repair the pipe which is defect [5]. However, these extremely advanced pipeline inspection robot is not been ordinary to the others country especially Malaysia because of its high cost. One fully equipped pipeline inspection robot costs around 20,000 - 35,000 dollars [6]. Therefore, an affordable pipeline inspection robot with high efficiency should be develop to meet the demand of the countries which have low percentage of pipeline explosion incident.

Next, efficiency is one of the main concerns of a pipeline inspection robot. In current technology, humans are not only need a robot that can perform the physical task but also chasing the high efficiency of the robot to solve the task in a shorter time. However, the evolution of the robotics field has been focused on the single robot systems which consume more time in solving a task compared to multi robot system. The move from single robot system to multi robot system is very important to develop a new era of technology. Multi robot system brings many benefits over single robot system in terms of efficiency, completion of time, and flexibility. Basically, a pipeline inspection robot is move slowly along the pipeline to check and monitor along the pipe. The robot need extra time especially the pipeline have a two ways like T branches. Therefore, the speed and accuracy of the mobile robot must be considered to improve the time efficiency of the pipeline inspection robot so that the inspection work can solved in a shortest time.

Besides, flexibility of the robots also is a main concern issue. In current technology, most of the multi robot system perform the homogeneous action mechanism. Homogeneous action mechanism means that a team of follower robots follow exactly the task that have done by the leader robot. The flexibility of the robots are low if compared to the heterogeneous action mechanism robot. There is a slightly different between two mechanisms. Both mechanism consist of a main robot but the slave robot in heterogeneous action mechanism can perform different task with the master robot. Some pipeline have a

two ways like T branches pipeline. In this case, heterogeneous action mechanism robot can perform well by perform the pipeline inspection simultaneously but different direction. Thus, flexibility of the robots must be considered to improve the efficiency of the pipeline inspection process.

In summary, this research will focus on developing a communication system between two mobile robots to perform the pipeline inspection with high efficiency and flexibility with the aid of low cost cooperative controlled robots.

#### **1.4 Objectives**

In this project, there are three objectives going to achieve:

1. To develop two affordable mobile robots that are cooperative controlled for pipeline inspection.
2. To evaluate the performance of the mobile robots in terms of speed, accuracy and efficiency.
3. To develop a communication system between the ‘master and slave’ robots by using the Bluetooth module for real time data transmission.

#### **1.5 Scope**

1. The robots consist of ultrasonic sensors, infrared sensors, Bluetooth module and the Arduino Uno board as the controller.
2. The size of the robots is 19cm x 13cm x 12cm.

3. There are two of the cooperative controlled robots is developed.
4. The mobile robots are applicable for the pipe where the diameter of the pipe is in the range of 20cm to 30cm.
5. The pipe is set up in horizontal.
6. The distance of the pipe to the junction is fixed to 2m.
7. The robots consists of camera which is specialized for data monitoring only. Robots are performed the task of live streaming in the pipe and capture image without image processing.
8. The mobile robots are applicable for the pipes which use to transport air or gas.

## **1.6 Summary**

Overall, there are 4 subtopics are discussed which are motivation of the project, problem statement, objectives and scope of the research. The objectives of this project is to design two affordable mobile robots that are cooperative controlled for pipeline inspection by using a camera to monitor the environment of the pipeline. Besides, this project also aims to develop a communication system between the master-slave robots by using the Bluetooth module for real time data transmission. Last but not least, to evaluate the performance of the pipeline inspection robots in terms of efficiency, speed and accuracy. The next chapter will discuss and summarizes the findings on previous journal related to the project.

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Introduction

In this chapter, the theoretical background which related to this project such as theories on multi robot system and pipeline inspection are presented. Many previous journals, conference papers and articles which related to this project are studied and analyzed. A summary table is then constructed to summarize the findings based on few specific criteria.

#### 2.2 Cooperative Controlled Robots

The phrase cooperative controlled robots also defined as multi robot system (MRS). MRS means a group of two or more mobile robots working together as a team to solve the tasks in the same environment [7]. Actually multi robots system is not a new technology. Since the late 1980s, researchers have been inspired to design and construct a set of robots which can working together to solve certain tasks [7]. At the beginning, researchers are motivated by observed the natural behavior of a swarm of ants and bees. From the observations, researchers are studied how a group of organism can working together to solve the problems. These early studies is important in contribution to develop the multi robot system nowadays. The studies also led to multi robot system being applied in different field such as surveillance, rescue, exploration, coordinate navigation, cooperative manipulation and among others [7]. The description of the application of MRS is summarize in Table 2.1.