FAKULTI KEJURUTERAAN ELEKTRIK

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LAPORAN PROJEK

SARJANA MUDA

CRAWLER TYPE ROBOT

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Bachelor of Mechatronics Engineering

June 2014

“I hereby declare that I have read through this report entitle “Crawler Type Robot” and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Mechatronics Engineering”

Signature : ……………………………………

Supervisor’s Name : ……………………………………

Date : ……………………………………

CRAWLER TYPE ROBOT

CHIA WEN YUNG

This Report Is Submitted in Partial Fulfillment of the Requirements for the Degree of Bachelor of Mechatronics Engineering

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2014

“I declare that this report entitle “Crawler Type Robot” is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : …………………………………….

Name : …………………………………….

Date : …………………………………….

To my beloved mother and father

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ABSTRACT

Nowadays, the crawler type robots are widely used in rescuing and inspection missions. Therefore, crawler type mechanism is kept improving so it can be applied on various type of terrains with better performance. However, most of the existing crawler type robots available now are not moving consistently in one direction. In other words, it cannot move according to our desired direction properly. This project is undertaken with the aim to design and develop a crawler type robot which can pass through several types of terrain as well as to analyze and evaluate the performance of developed crawler type robot in term of its accuracy and repeatability. The scope of this project is focused on the performance test of robot's accuracy and repeatability with respect to its speed on regular and irregular terrains. Moreover, the terrains involved in this project are focus only on flat surface, rough surface and stairs as well. This project presents the analysis of the developed crawler type robot's performance by collecting the data during the experiment. The experiment conducted here consists of two research methodologies: lab test and field test. Lab test is conducted on flat surface and stairs while field test is conducted on rough surface. Both of the experiments measure the performance (accuracy and repeatability). Besides that, the robot was also been tested on its capability of climbing the stairs. However the study was limited only to the flat surface, rough surface and stairs. For recommendation, it should cover the study of suspension system on more irregular terrains with extreme conditions such as underwater, sand and mud. Moreover, it should also include different types of controller such as PI, PD and PID controller.

ABSTRAK

Sejak kebelakangan ini, robot jenis merangkak telah digunakan secara meluas dalam misi menyelamat dan pemeriksaan. Oleh itu, mekanisme tersebut terus diperbaiki supaya ia dapat digunakan di atas pelbagai bentuk permukaan bumi dengan prestasi yang lebih baik. Walau bagaimanapun, kebanyakan robot yang sedia ada pada masa kini tidak dapat bergerak pada satu arah secara konsisten. Projek ini dijalankan dengan tujuan untuk mereka bentuk dan menghasilkan robot yang berupaya untuk bergerak di atas pelbagai jenis bentuk permukaan bumi. Selain itu, objektif tersebut juga merangkumi penilaian robot semasa ia beroperasi dari segi ketepatan dan kebolehulangan. Skop untuk projek ini hanya fokus terhadap ujian prestasi robot di atas permukaan rata, kasar dan tangga sahaja. Projek tersebut menunjukkan analisis prestasi robot dengan mengumpul data semasa eksperimen dijalankan. Terdapat two jenis penyelidikan metodologi dalam project ini, iaitu ujian makmal dan ujian lapangan. Ujian makmal dijalankan pada permukaan rata manakala ujian lapangan dijalankan di atas permukaan kasar. Kedua-dua eksperimen menilai prestasi robot (ketepatan dan kebolehulangan). Selain itu, ujian kebolehan robot untuk menaiki tangga turut dijalankan. Walau bagaimanapun, kajian tersebut adalah terhad kepada permukaan rata, kasar dan tangga sahaja. Sebaliknya, kajian ini harus merangkumi sistem penggantungan di atas pelbagai jenis bentuk permukaan yang lain seperti dalam air, padang pasir, dan lumpur. Selain itu, pelbagai jenis pengawal seperti PI, PD dan PID juga harus dikaji.

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CHAPTER 1

INTRODUCTION

1.1. Motivation

Japan was recognized as one of the advanced countries nowadays due to its rapid development of technologies. But unfortunately, an unwanted incident occurred on March 11, 2011. The earthquake with Richter magnitude scale of 9.0 causes a tsunami which hit the Tohoku area in Japan. As a result, several nuclear plants were damaged and the radioactive materials were spread out widely nearby those areas. [22]

The extreme situation makes the rescue and inspection missions more difficult to be performed at that time due to high radiation environment. Therefore, they decided to use mobile robots to perform the tasks instead of human beings because human cannot be exposed to highly radioactive materials for long period of time. [22]

Figure 1.1 shows the rescue mobile robots, named Quince robots which designed for searching and rescuing mission purposes. Quince robot consists of 4 crawler legs which are flexible to move over any type of terrains. Besides that, the mechanism of this robot also makes it to able to climb over the stairs. However, the movement of climbing the stairs might be slow if compared to its movement on the ground.

Figure 1.1 Quince robots [22]

Figure 1.2 shows the statistics of human and economic losses in Japan due to the disasters that happened since year 1980 to 2010. It shows that 157 of events were occurred within this 31 years and 8 568 people were killed. Average people killed per year are about 276 people. However, the economic damage is about 208 billion US dollars over 31years of natural disasters. There were nearly 6.7 million US dollars of economic damage per year in Japan due to the disasters. [18]

Natural Disasters from 1980 - 2010

Overview

No of events:	157
No of people killed:	8,568
Average killed per year:	276
No of people affected:	3,361,979
Average affected per year:	108,451
Economic Damage (US$ X 1,000):	208,230,800
Economic Damage per year (US$ X 1,000):	6,717,123

Figure 1.2 Natural disasters from year 1980 to 2010 [18]

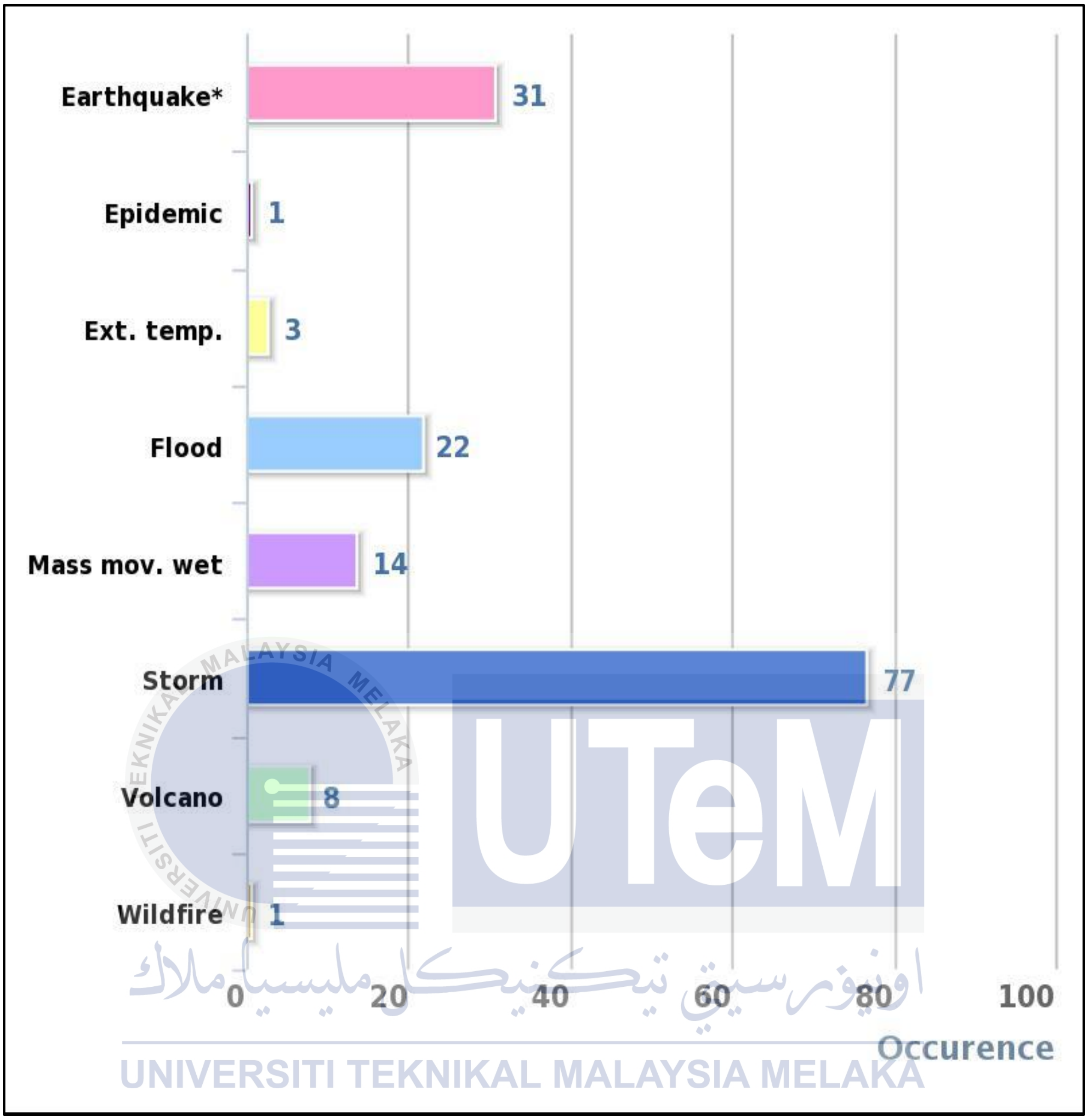
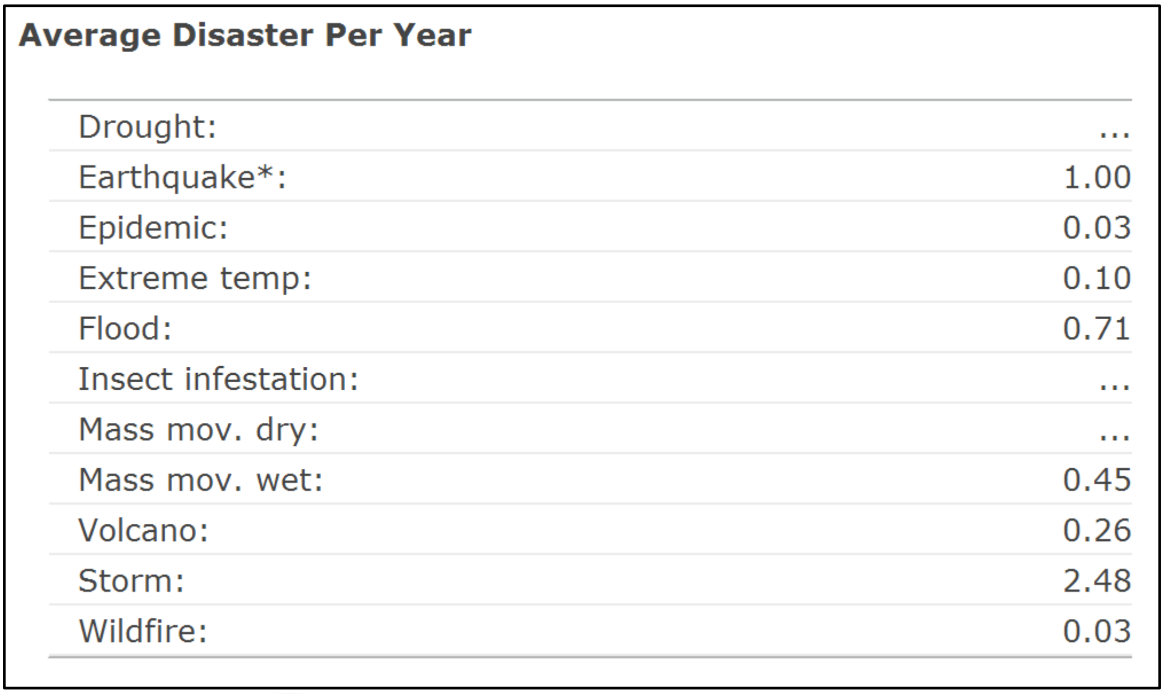


Figure 1.3 Natural disaster occurrence reported [18]

Figure 1.3 shows the statistics of natural disaster occurrence reported in year 1980 to 2010. The highest occurrence was the storm (77 occurrences) and earthquake was in second place (31 occurrences) after storm. Then follow by the flood which contributes to 22 occurrences. Figure 1.4 shows the average disaster per year based on the data in Figure 3.1.

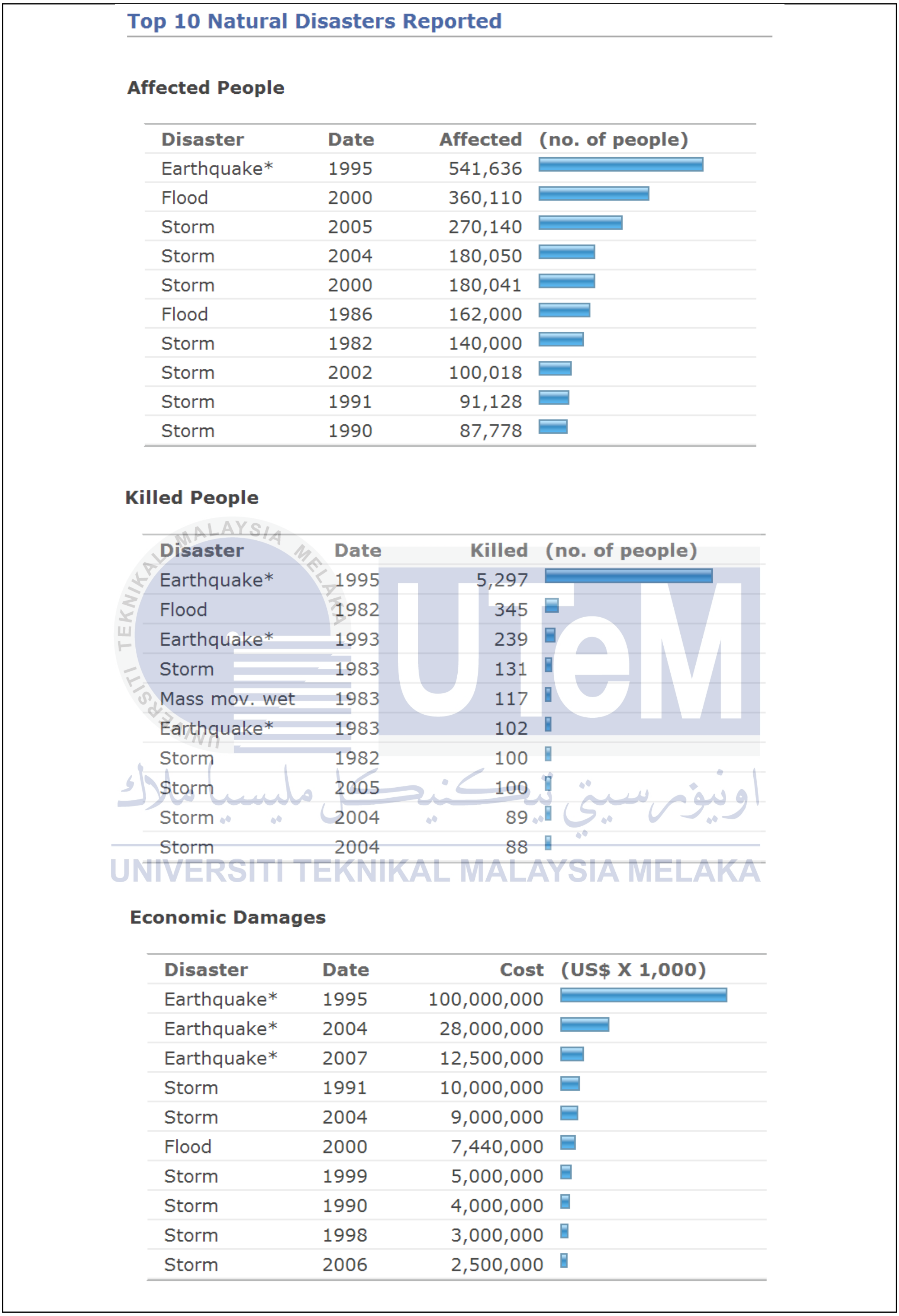


Average Disaster Per Year

Drought:	...
Earthquake*:	1.00
Epidemic:	0.03
Extreme temp:	0.10
Flood:	0.71
Insect infestation:	...
Mass mov. dry:	...
Mass mov. wet:	0.45
Volcano:	0.26
Storm:	2.48
Wildfire:	0.03

Figure 1.4 Average disasters per year [18]

Figure 1.5 shows the data of top 10 natural disasters reported based on 3 categories: affected people, killed people and economic damages. The highest number of people affected and killed due to natural disasters was the earthquake. Earthquake contributes also the most severe economic damage to Japan. Figure 1.6 shows the statistics per event based on data in Figure 1.5.



Top 10 Natural Disasters Reported

Affected People

Disaster	Date	Affected	(no. of people)
Earthquake*	1995	541,636	
Flood	2000	360,110	
Storm	2005	270,140	
Storm	2004	180,050	
Storm	2000	180,041	
Flood	1986	162,000	
Storm	1982	140,000	
Storm	2002	100,018	
Storm	1991	91,128	
Storm	1990	87,778	

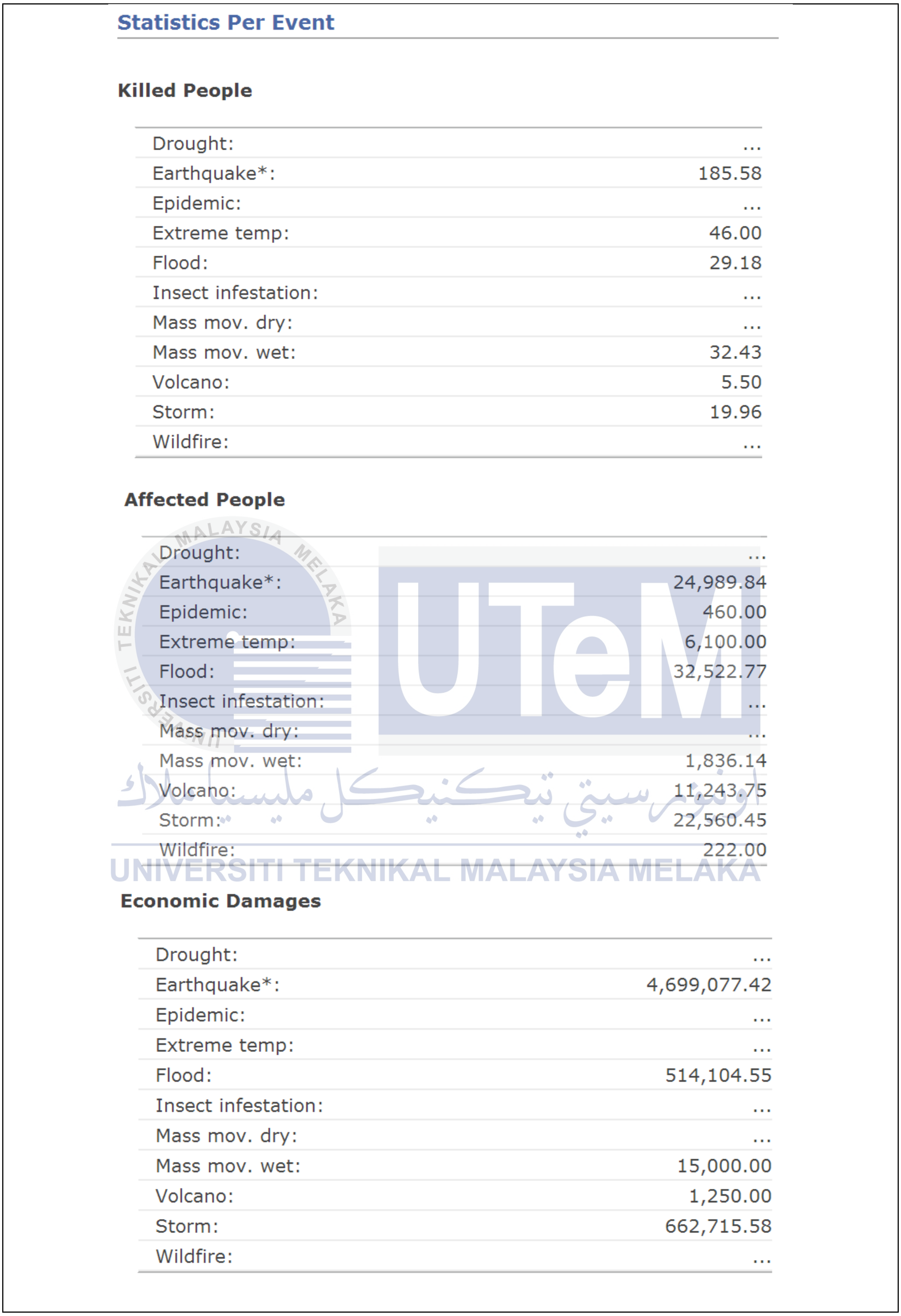
Killed People

Disaster	Date	Killed	(no. of people)
Earthquake*	1995	5,297	
Flood	1982	345	
Earthquake*	1993	239	
Storm	1983	131	
Mass mov. wet	1983	117	
Earthquake*	1983	102	
Storm	1982	100	
Storm	2005	100	
Storm	2004	89	
Storm	2004	88	

Economic Damages

Disaster	Date	Cost	(US$ X 1,000)
Earthquake*	1995	100,000,000	
Earthquake*	2004	28,000,000	
Earthquake*	2007	12,500,000	
Storm	1991	10,000,000	
Storm	2004	9,000,000	
Flood	2000	7,440,000	
Storm	1999	5,000,000	
Storm	1990	4,000,000	
Storm	1998	3,000,000	
Storm	2006	2,500,000	

Figure 1.5 Top 10 natural disasters reported [18]



Statistics Per Event

Killed People

Drought:	...
Earthquake*:	185.58
Epidemic:	...
Extreme temp:	46.00
Flood:	29.18
Insect infestation:	...
Mass mov. dry:	...
Mass mov. wet:	32.43
Volcano:	5.50
Storm:	19.96
Wildfire:	...

Affected People

Drought:	...
Earthquake*:	24,989.84
Epidemic:	460.00
Extreme temp:	6,100.00
Flood:	32,522.77
Insect infestation:	...
Mass mov. dry:	...
Mass mov. wet:	1,836.14
Volcano:	11,243.75
Storm:	22,560.45
Wildfire:	222.00

Economic Damages

Drought:	...
Earthquake*:	4,699,077.42
Epidemic:	...
Extreme temp:	...
Flood:	514,104.55
Insect infestation:	...
Mass mov. dry:	...
Mass mov. wet:	15,000.00
Volcano:	1,250.00
Storm:	662,715.58
Wildfire:	...

Figure 1.6 Statistics per event [18]

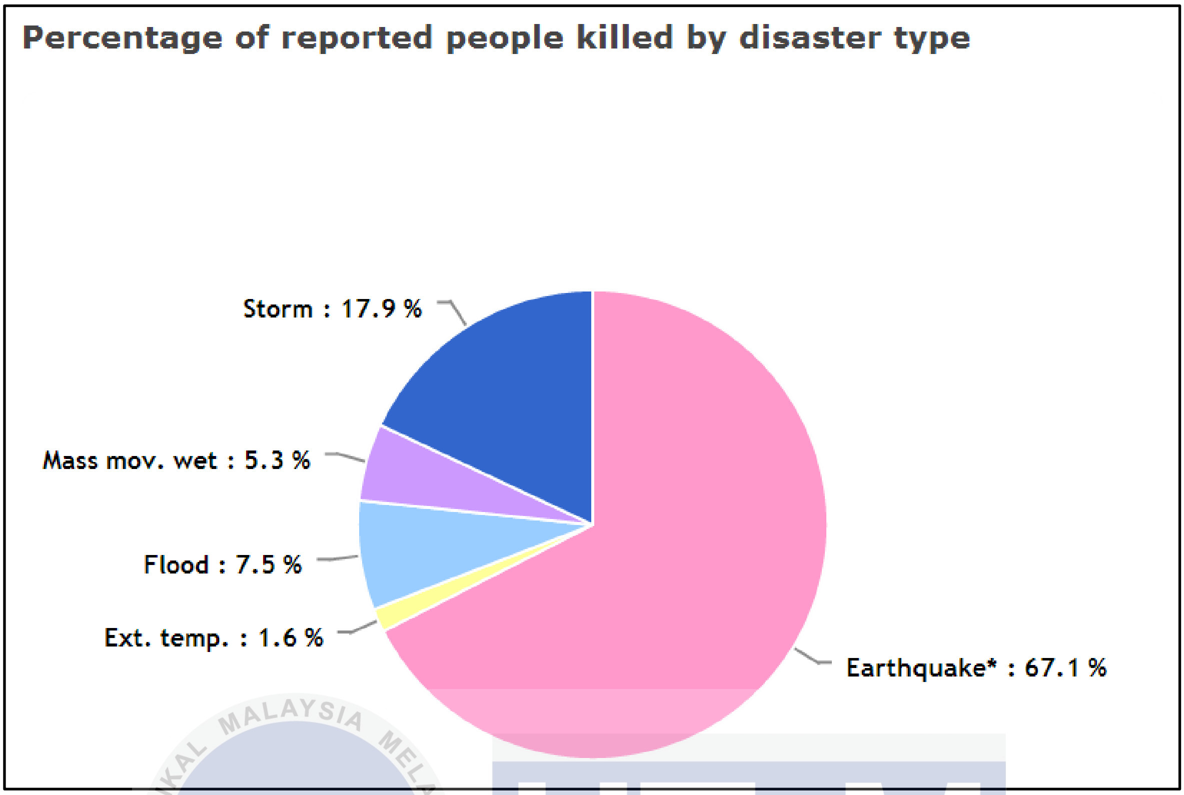


Figure1.7 Percentage of reported people killed by disaster type [18]

Figure 1.7 shows the statistics of reported people killed by disaster type in term of pie chart. Earthquake contributes the highest portion of this pie chart which constitutes of 67.1% of the pie chart. However, storm constitutes of 17.9% of the pie chart, follow by the flood (7.5%), mass movement wet (5.3%) and extreme temperature contributes the least portion of the pie chart, which is only 1.6% of the pie chart.

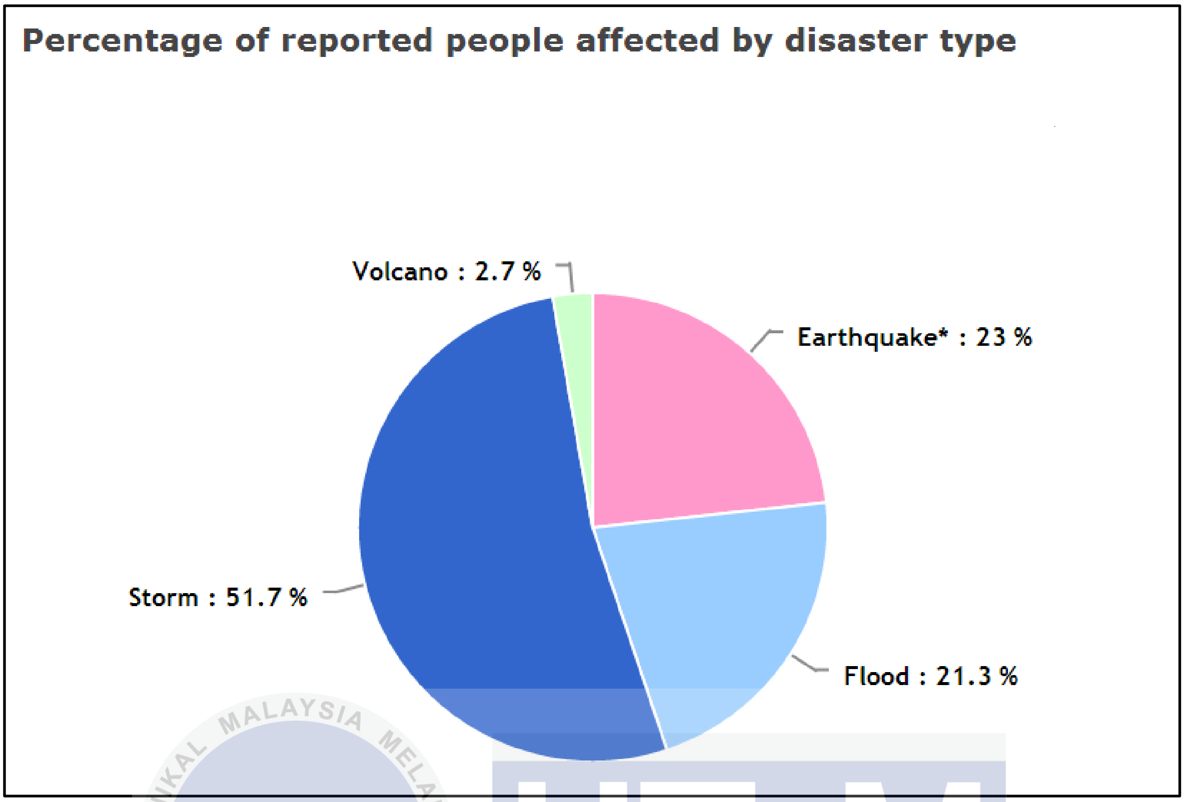


Figure 1.8 Percentage of reported people affected by disaster type [18]

Figure 1.8 shows the statistics reported people affected by disaster type in term of pie chart. Storm contributes the highest portion of this pie chart which constitutes of 51.7% of the pie chart. However, earth quake constitutes of 23% of the pie chart, follow by the flood (21.3%) and volcano contributes the least portion of the pie chart, which is only 2.7% of the pie chart.

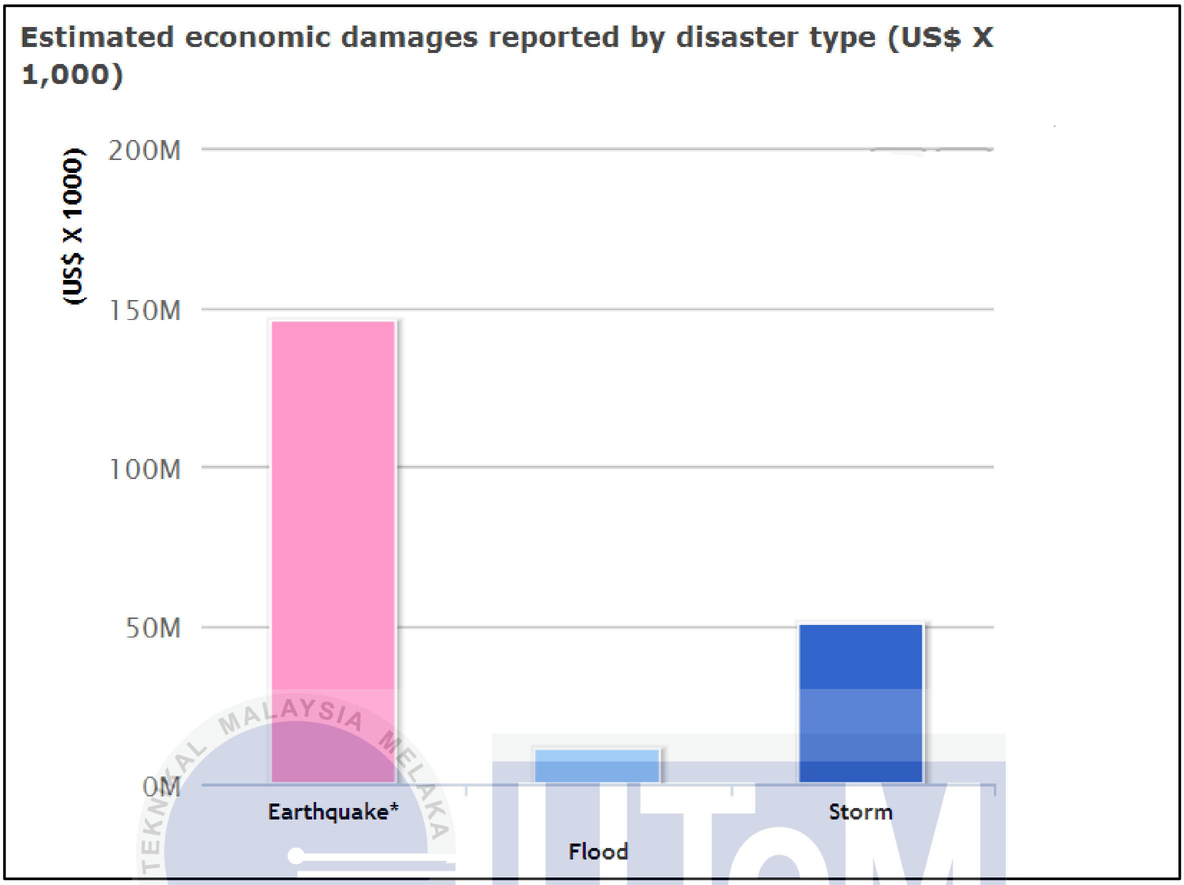


Figure 1.9 Estimated economic damages reported by disaster type [18]

Figure 1.9 shows the statistics on estimated economic damages reported by disaster type in term of bar chart. The highest estimated economic damages reported is by earthquake, which is nearly 145 billion US dollars. Then follow by storm, around 51 billion US dollars. The lowest economic damages reported is by flood, which is around 11 billion US dollars only.

Nowadays, mobile robots really play a significant role in our daily lives because it can assist us to solve the problems which cannot be solved directly from human beings. Besides that, it could also reduce the probability of human beings to get injured. Therefore, a research on mobile robots should be further studied in order to improve our future quality of life.

1.2. Problem Statement

There are variety types of locomotion available for a robot to move and crawler is one type of it. Crawler type mechanism can be applied on various terrains, this is the reason why human is using crawler type robot to do the dangerous tasks in extreme condition such as rescuing and inspection missions.

However, the crawler type robot is not easy to be developed because it requires the use of fundamental mechatronics engineering knowledge, especially on irregular terrains. There are a lot of things that need to be taken into consideration during development of a robot such as mechanism, electrical circuit, control system and computer programming as well.

Moreover, most of the existing crawler type robots available now are not moving consistently in one direction. In other words, the speed of both motors is different from each other even though the output power for both motors is the same, which means the motors speed for both side are not synchronize together. Besides that, it might be due to the miss-alignment of the crawler belt. As a result, the robot will move slightly deviate from the desired route. If this condition is still persisting, then it might affect the overall performance and efficiency of the robot and also might bring a hazard to human. Therefore, it needs to be improved its accuracy and repeatability or maintain the speed for both sides of motors during the operation of robot.

1.3. Objectives

The objectives of this project are:

1. To design and develop a crawler type robot which can pass through several types of terrains.
2. To analyze and evaluate the performance of fabricated crawler type robot in term of its accuracy and repeatability.

1.4. Scope

This project is focused on the performance test of robot's accuracy and repeatability on regular and irregular terrains. The terrains involved in this project are focus only on:

1. Flat surface.
2. Rough surface.
3. Stairs.

CHAPTER 2

LITERATURE REVIEW

2.1. Crawler Type Robots

Based on the paper done by S. Yokota et al., they mentioned about leg-type crawler robot on irregular terrain. They have proposed "leg-type crawler" mechanism for their robot which consists of crawler mechanism and walking mechanism. Therefore, it can switch the moving modes according to the terrain. However, it consists a lot of motors which could need a huge power supply for the operation. Therefore, the number of motors required need to be taken into consideration when design the crawler robot. Besides that, it takes time when climbing the stairs. Figure 2.1 shows the leg-type crawler robot. [20, 21]

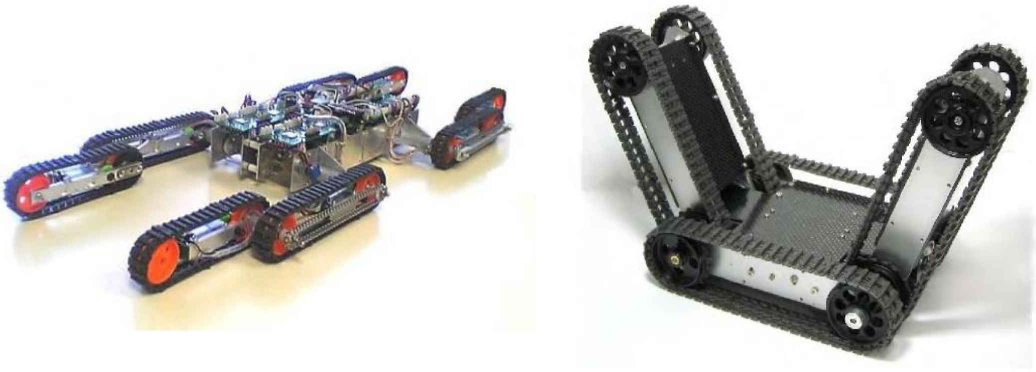


Figure 2.1: Leg-type crawler robot [20, 21]

In addition, the paper prepared by K. Tadakuma et al. mentioned about the omni-crawler with circular section. They have designed a new mechanism for the crawler type robot based on the concept of omni-directional mobile robot. With a conventional crawler robot, it has to turn round repeatedly to enter a narrow space. However, this kind of crawler type robot is differed from the conventional crawler robot. It can make a sideways movement easily, so it does not require too much energy to make the turning movement. Therefore, the energy loss can be greatly reduced by using this mechanism. Besides that, it could also perform step climbing, moving on and inside the pipe and moving on soft grounds. Figure 2.2 shows the crawler vehicle. [17]

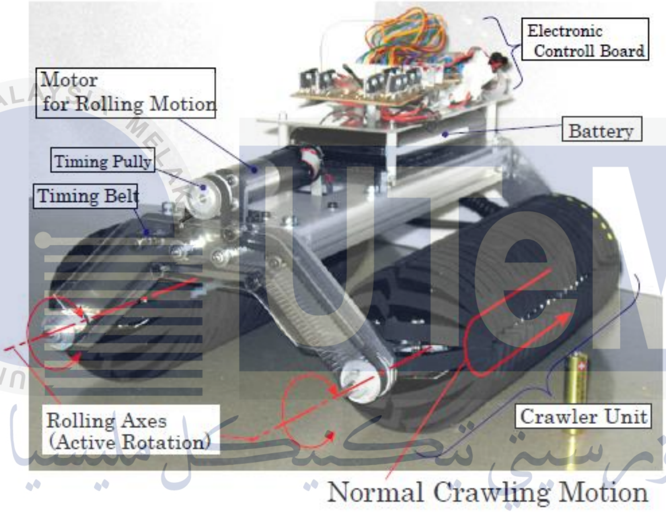


Figure 2.2: Crawler vehicle [17]

Furthermore, based on the paper written by J. Nagase, K. Suzumori and N. Saga, they explained about the cylindrical crawler robot using worm rack mechanism. They have claimed that cylindrical crawler robot is able to move in confined space such as under rubble or thin pipe compared to conventional crawler robots. However, it can only move in forward and backward directions, but not in lateral movement. Omni-crawler mechanism actually can be implemented in cylindrical crawler unit but it is quite difficult due to its complicated structure. Figure 2.3 shows the cylindrical crawler robot. [12]

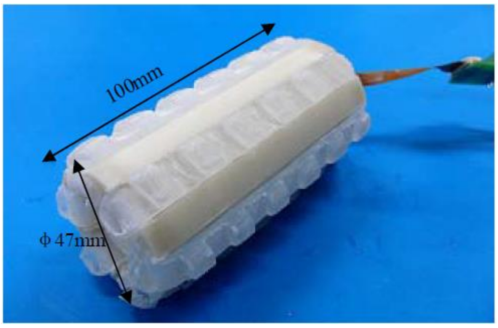


Figure 2.3: Cylindrical crawler robot [12]

Besides that, T. Yamawaki, T. Omata and O. Mori proposed the parallel mechanism on mobile robots with 4 and 5 degree of freedom in their paper. This paper presents the integration of parallel mechanism with the crawler mechanism in mobile robot. The combination of these two mechanisms brings advantages such as move over the vertical bump by controlling its center of gravity and carrying a load by transforming its shape. In Figure 2.4, the frictional force is required to move over the steps. While in Figure 2.5, the robot is able to move over the steps easily with the aid of parallel mechanism. [19]

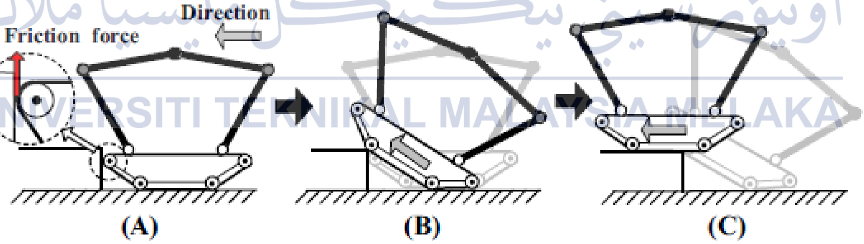


Figure 2.4: Sequence of passing over steps [19]

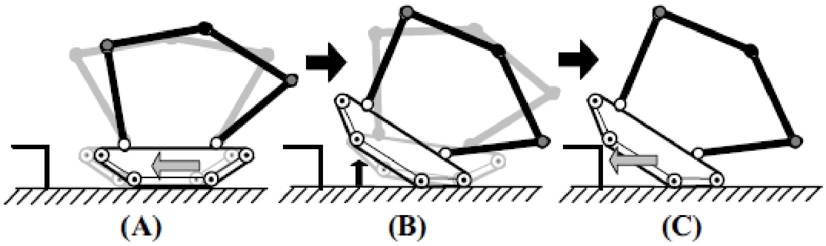


Figure 2.5: Sequence of raising front end [19]

In the paper written by G. P. Lan, S. G. Ma and K. Inoue, they have proposed the crawler robot for irregular terrain purpose. They introduced a rotatory crawler mechanism for mobile robot in order to move on irregular terrains. Normally crawler-type robots are better than wheeled or leg-type robots because it has off-road capability. Planetary gear reducer was used in this invention because it can provide two different outputs with one actuator only. Figure 2.6 shows the mobile robot can operated as vehicle on flat surface as well as climb over the stairs by rotating its crawlers together. [2]

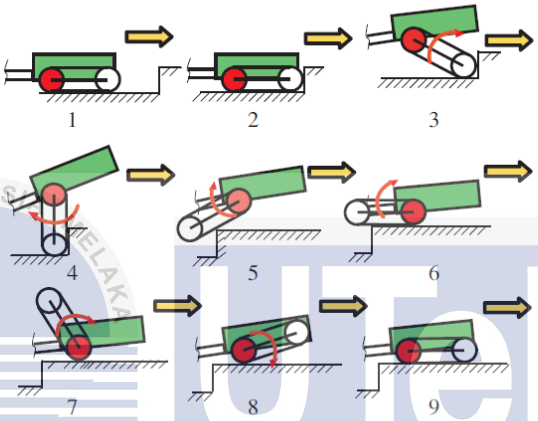


Figure 2.6: Process of moving over the step for single rotatory crawler unit [2]

Meanwhile, the motion study conducted by T. Inoue, K. Takagi and T. Shiosawa is about the crawler-type remotely operated vehicle (ROV). They claimed that a crawler robot can be functioned in the sea with irregular terrain and sand. The robot operating on seabed is totally different from land due to several factors such as buoyancy, slippage and hydrodynamic force. These parameters are significantly affect the performance and mobility of the robot. Therefore, they have conducted an experiment and came out with the useful mathematical model for this dynamic analysis. [5, 6, 7]

Moreover, a study of crawler robot with adjustable steering radius was conducted by Štatkić, S., Jeftenić, B. and Bebić, M.. They have claimed that the outer motor of the crawler will experiencing larger burden or load during turning or steering movement. This load was come from the friction and turning torque. When the robot wants to perform turning motion, normally only one motor will be operated and the other one will act as brake. This was not a good idea since all the load will goes to the operating motor and it will decrease the efficiency. However, there is another method which using the controlled drives where the speed could be adjusted properly. Therefore, adjustable steering radius could be obtained by giving adjustable speed difference between each motor. Controlled drives could also protect the motors from overload. [16]

Table 2.1 shows the advantages and disadvantages of each crawler type robot found in journals in term of its functionality.

Table 2.1 Review of each crawler type robot

Journal	Advantages	Disadvantages	Evaluation
Leg-type crawler robot on irregular terrain	• Can switch moving mode according to terrain.	• Time taken to climb or move is long.	Poor
Omni-crawler with circular section	• Less power consumption. • Move sideways easily.	• Hard to climb the stairs.	Good
Cylindrical crawler robot using worm rack mechanism	• Able to move in confined space.	• Cannot move in lateral movement.	Moderate
Parallel mechanism on mobile robots with 4 and 5 degree of freedom	• Able to move over the steps easily.	• Complex structure due to many of DOF.	Moderate
Crawler robot for irregular terrain purpose	• Has off-road capability. • Can climb over the stairs.	• None	Moderate
Crawler-type remotely operated vehicle (ROV)	• Can function in the sea.	• Low performance and mobility.	Poor
Crawler robot with adjustable steering radius	• Adjustable steering radius. • Protect the motors from overload.	• None	Good

2.2. Features and Mechanism

Based on the paper written by J. H. Zhu et al. describe about the mobile robot design for rough terrain. They have designed a suspension system for the robot to move steadily on the rough terrain so that it can carry things more stable. This feature is very useful when using to carry fragile and sensitive goods. Figure 2.7 shows the front and rear suspension system. [10]

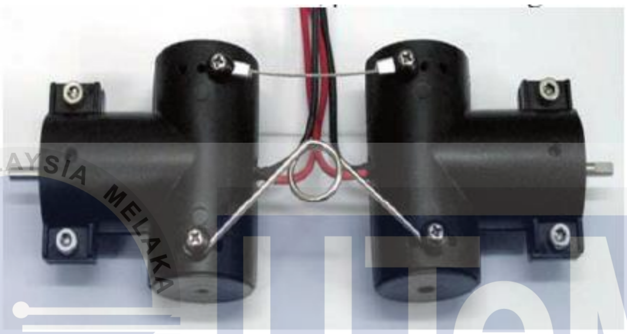


Figure 2.7: Front and rear suspension system [10]

Besides that, the paper done by H. Q. Wang, A. Yamamoto and T. Higuchi presents about the electrostatic-motor- driven electroadhesive robot. They have introduced a new climbing robot consists of locomotion and adhesion features using the concept of electrostatic force. Electrostatic adhesion has advantages over other adhesion techniques such as air pressure and magnetic force. Air pressure adhesion normally requires a huge air pump and produce noises while magnetic force can only functions on magnetic surface. Therefore, electrostatic adhesion technique was introduced because it can works on non-conductive surface. Besides that, it does not involve any heavy materials such as ferromagnetic materials, so the structure of the robot is light. Figure 2.8 shows the structure of flexible climbing robot. [3]

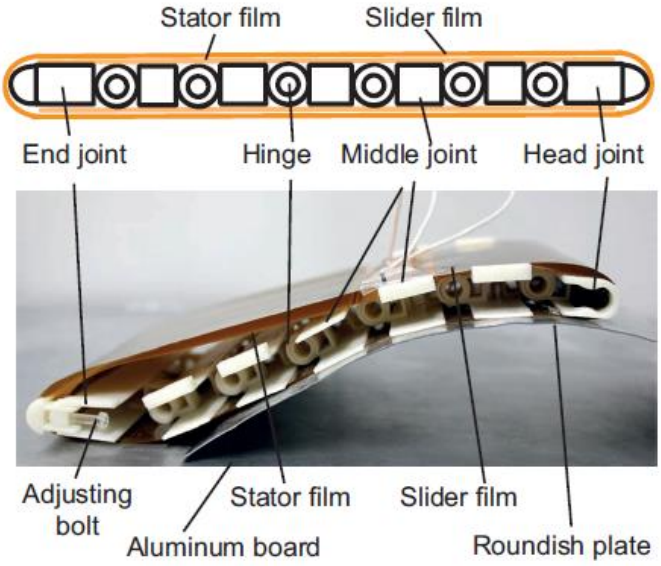


Figure 2.8: Flexible climbing robot [3]

In addition, the research conducted by R. Hayashi et al. is about the torque transfer characteristics of flexible shafts. Since most of the crawler-type rescue robots are working under extreme condition such as high humidity and confined space, so the electrical components installed on the robot might get damaged easily. The usage of flexible shafts on crawler robot was proposed because it can reduce or eliminate the installation of electrical components on the robot. The flexible shaft is used to transmit the rotary motion between power source (electric motor) and both side of the crawler (gears) where the relative position are vary to each other. However, the performance of the robot will be affected significantly when the flexible shaft made a few loops or in contact with obstacles. Figure 2.9 shows the crawler type robot with improved flexible shaft. [4]

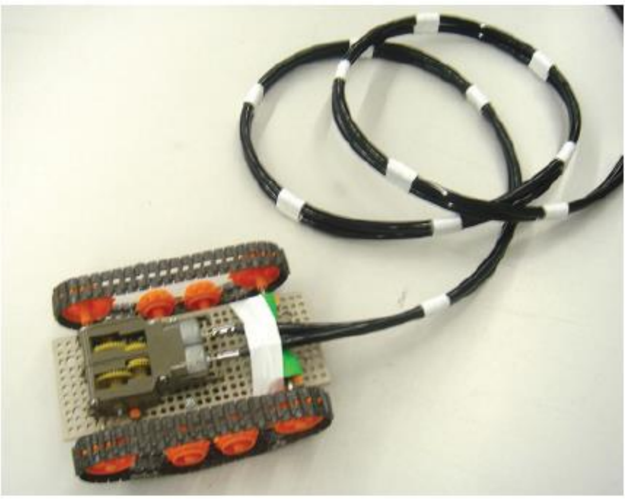


Figure 2.9: Crawler type robot with improved flexible shaft [4]

Furthermore, D. Inoue et al. had done a research on the contact points detection for tracked mobile robot. Most of the crawler robots with high stability and mobility properties are able to move over any rough terrain. However, it is quite difficult for the operator to control the high mobility robot. Therefore, the authors proposed a semi-autonomous control system in order to make the handling operation easier by implementing the contact sensors on crawler chain. In this system, the crawlers will automatically adapt to the environments, so the user only needs to control the direction of the robot's movement. Figure 2.10 shows the structure of the crawler. [8, 9]

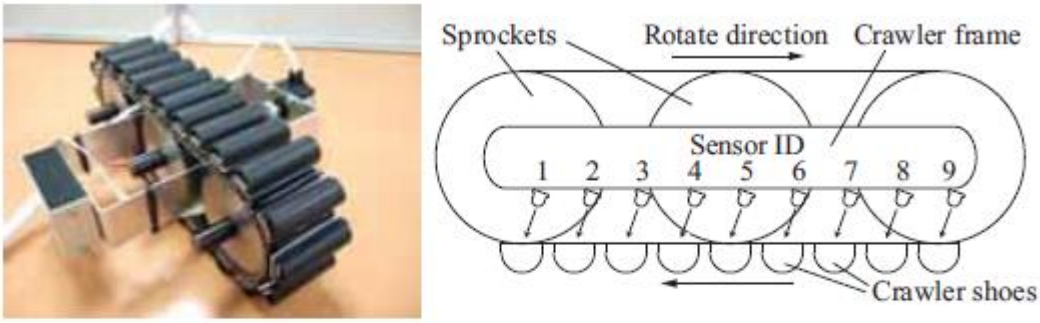


Figure 2.10: Crawler [8, 9]

Furthermore, Santora, M., Alberts, J. and Edwards, D. prepared a paper entitled "Control of Underwater Autonomous Vehicles Using Neural Networks" which describes the advantages of using neural networks on underwater vehicle. As we know, the environmental conditions between water and land are totally different. Therefore, there are many factors that need to be considered about when develop an underwater vehicle. Neural Network and Fuzzy Logic Controller are under artificial intelligent control system. It has the ability to differentiate and analyze the environmental conditions (input) and create a suitable solution (output). Therefore, neural network controller was chosen as it can adapt the variable conditions that occurred underwater. [15]

On the other hand, a study about the dual-crawler-driven robot mechanical design and posture control has been carried out by Q. Q. Quan et al.. This paper discusses the usage of power transmission device in the robot, which is the planetary gear reducer. The benefit of planetary gear reducer is that one actuator can produce two different outputs. Wheeled robots can move easily on smooth surface but not on rough terrains. While leg-type robots can move properly on irregular surfaces but less stable and hard to control. However, crawler-type robots have the advantages on irregular terrains due to its high stability, ease to control and low pressure exerts on the surface. To enhance the mobility of a robot, additional devices or components are required. However, it will bring extra burden to the robot and needs more energy to operate. Therefore, crawler mechanism with polymorphic mechanism is used, because it equipped with planetary gear reducer which using one actuator to produce two outputs. The crawler robot will overcome the obstacles automatically by switching two types of locomotion modes. [13, 14]

On the other hand, the paper prepared by T. Arai mentioned about the necessity of integration of locomotion and manipulation on a robot. This paper pointed out that a robot should be able to move around to perform its task rather than just working at stationary position. A robot system with manipulation and locomotion functions will help human a lot when performs outdoor tasks. However, development of a robot system is not an easy task because it needs to consider about the performance such as efficiency, accuracy, reliability, speed and etc. [1]

Table 2.2 reviews the features and mechanisms found in journals in term of its benefits and drawbacks.

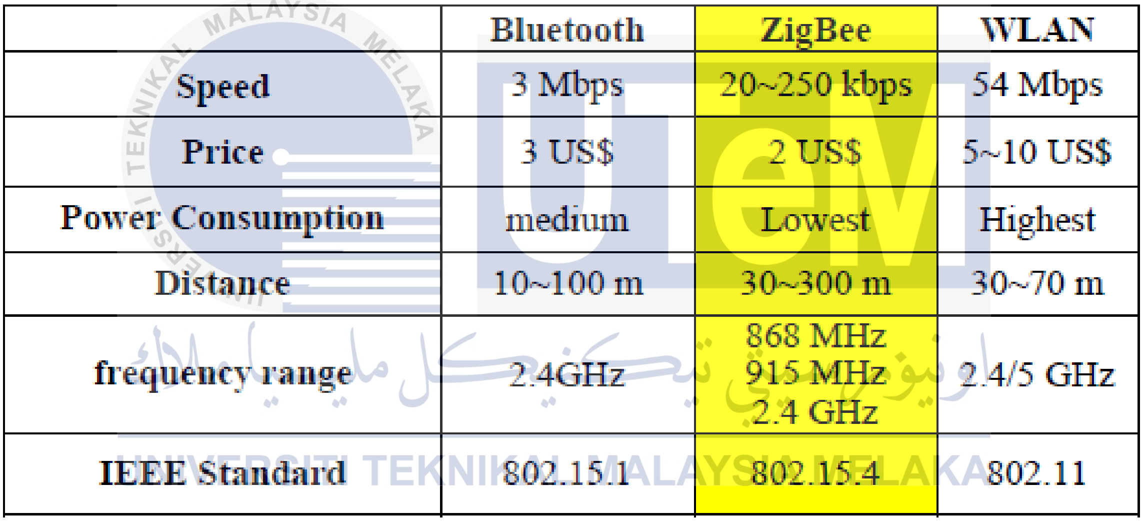
Table 2.2 Advantages and disadvantages of each feature or mechanism

Journal	Advantages	Disadvantages	Evaluation
Mobile robot design for rough terrain	• Can move steadily. • Can carry things more stable.	• Apply mostly in wheel-type mobile robot and hard to implement in crawler-type.	Moderate
Electrostatic-motor-driven electroadhesive robot	• Can works on non-conductive surface. • Structure is light.	• Cannot apply in heavy robot.	Poor
Torque transfer characteristics of flexible shafts	• Flexible shaft. • Reduce the needs of installation of electrical part in robot.	• Easy to made a loops or in contact with obstacles.	Poor
Contact points detection for tracked mobile robot	• Semi-autonomous control system.	• None	Good
Using neural networks on underwater vehicle	• Able to differentiate and analyze environmental conditions.	• None	Good
Dual-crawler-driven robot mechanical design and posture control	• Can produce two different outputs with one actuator.	• None	Good
Necessity of integration of locomotion and manipulation on a robot	• Integration of manipulation and locomotion functions.	• Not easy to develop.	Good

2.3. Wireless Technology

Based on the paper written by K.H. Lin, H.S. Lee and W.T. Chen, mentioned about the implementation of ZigBee control functions for mobile robot. They claimed that ZigBee was the best wireless communication system compared with Bluetooth and wireless local area network (WLAN). ZigBee was widely used in wireless communication system due to its low power consumption and cheap. Table 2.3 shows the wireless technology comparison. [11]

Table 2.3: Wireless technology comparison [11]



	Bluetooth	ZigBee	WLAN
Speed	3 Mbps	20~250 kbps	54 Mbps
Price	3 US$	2 US$	5~10 US$
Power Consumption	medium	Lowest	Highest
Distance	10~100 m	30~300 m	30~70 m
frequency range	2.4GHz	868 MHz 915 MHz 2.4 GHz	2.4/5 GHz
IEEE Standard	802.15.1	802.15.4	802.11

2.4. Conclusion

Table 2.4 compares each of the crawler type robots in terms of its speed, power consumption, moveable environment and ability to perform certain task.

Table 2.4 Crawler type robot comparison

Journal	**Speed**	**Power consumption**	**Moveable environment**	**Able to climb stairs**	**Able to move sideway**	**Able to carry loads**	**Able to use for inspection**
Leg-type crawler robot on irregular terrain	Slow	High	Land	Yes	No	No	Yes
Omni-crawler with circular section	Fast	Less	Land	No	Yes	No	Yes
Cylindrical crawler robot using worm rack mechanism	Slow	Less	Land	No	No	No	Yes
Parallel mechanism on mobile robots with 4 and 5 degree of freedom	Slow	High	Land	Yes	No	No	Yes
Crawler robot for irregular terrain purpose	Fast	High	Land	Yes	No	No	Yes
Crawler-type remotely operated vehicle (ROV)	Slow	High	Underwater	No	No	No	Yes
Crawler robot with adjustable steering radius	Fast	Less	Land	No	No	No	Yes

CHAPTER 3

METHODOLOGY

This chapter will discuss mainly on project and research methodologies. Project methodology will mention and discussing on the methods and procedures of project development. While research methodology will discussing on the methods of evaluate the project.

3.1. Project Methodology

This project will divided into three phases as following:

1. Project initialization.
2. Project development.
3. Project evaluation.

3.1.1. Project Initialization

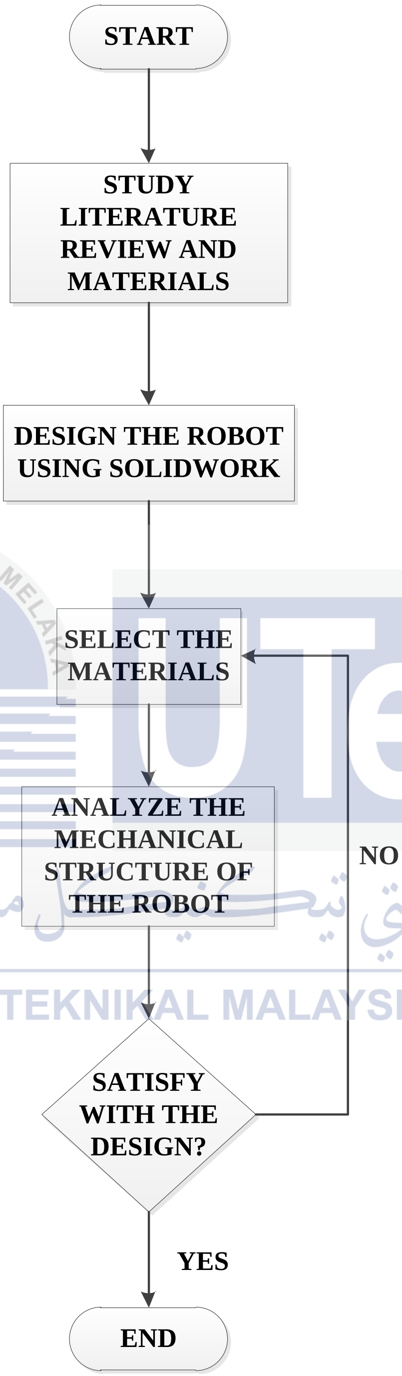


Figure 3.1 Project initialization flowchart

Figure 3.1 shows the flowchart of the project initialization. In the phase of project initialization, the project is started with a problem statement and the objectives as well as the scope were defined. Then, study of literature review and materials selection was carried out before proceed to next step. Next, the design of the crawler type robot was start to develop using SolidWorks CAD software. After that, analysis of robot's mechanical structure was performed to ensure the materials selected were not deformed easily due to the force or load exerted on the structure of the robot. Besides that, the design of the robot's structure must be analyzed also to study the force and stress elements. If the design was satisfied, then it can be proceed to next phase. However, the materials selection and analysis need to be carried out again if the design is not satisfied.

Figure 3.2 shows the conceptual design of crawler type robot. This crawler type robot design basically consists of 4 main items: Direct Current (DC) motors, crawler belts, pulleys and body structure. However, there are some other auxiliary items needed also in contributing to the design of crawler type robot and it will be listed out inside the Bill of Materials (BOM) list in Table 3.2. The detail drawing of the robot was shown in APPENDIX A.

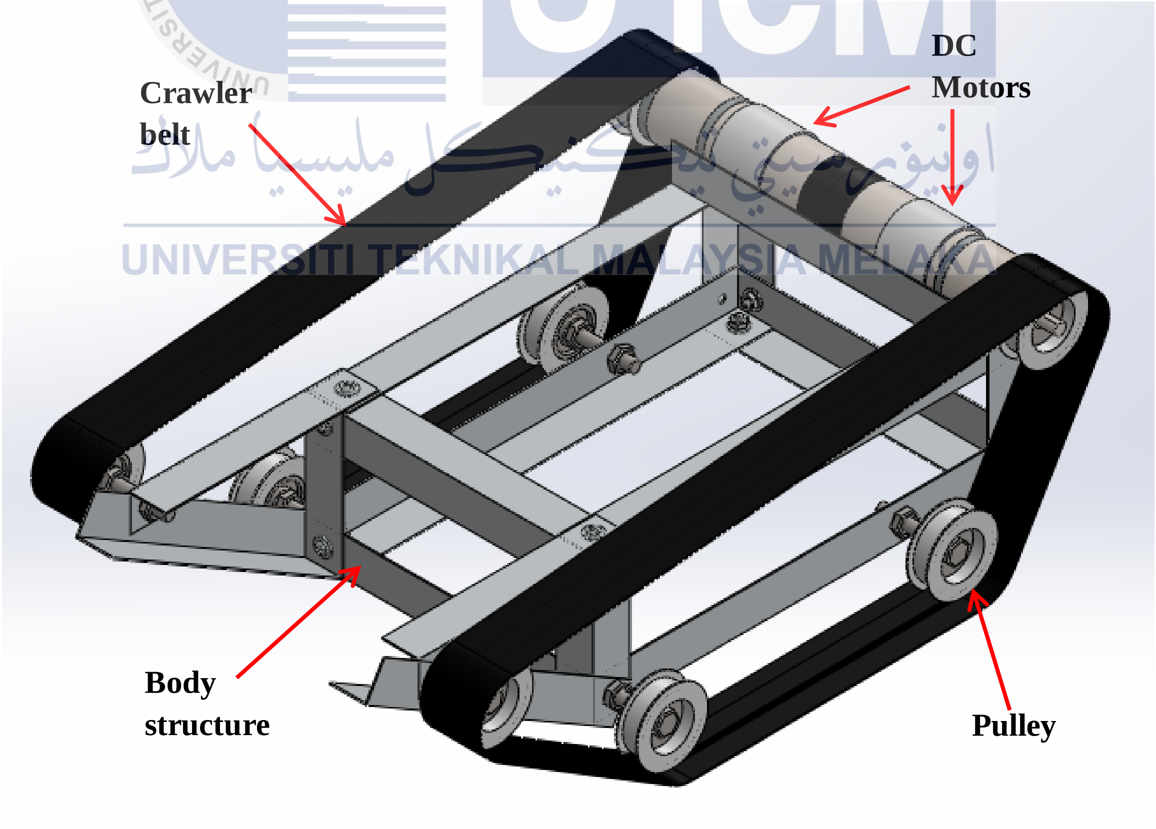


Figure 3.2 Conceptual design

Table 3.1shows the materials selection for developing the crawler type robot. The body structure of the crawler type robot was constructed using L-bar or angled bar which is made of aluminium material. However, the body cover of the robot was made using transparent PVC sheets. The purpose of using transparent PVC sheet is to give a clear visualization inside the robot. Therefore, it is easier for the troubleshooting task. Besides that, a plastic pulleys were used instead of using metal pulley because plastic material is much lighter than metal. The last component was the crawler belt, which using rubber material because it can provide a sufficient friction and grip force to make the robot moves and climbs the stairs without slippage.

Table 3.1 Materials selection

Part	**Material**
Body cover	PVC Sheet
Body structure	Aluminium L-bar
Pulley	Plastic
Crawler belt	Rubber

3.1.2. Project Development

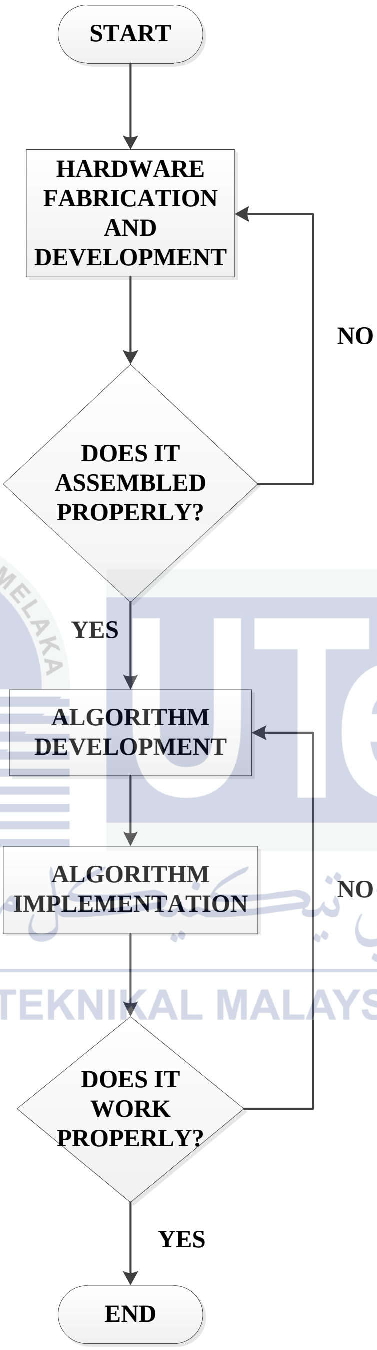


Figure 3.3 Project development flowchart

Figure 3.3 shows the flowchart of project development. In the phase of project development, the parts of the robot were fabricated based on the design and materials selection done in previous phase. Then, the fabricated parts were brought together for the assembly process. This is the place where the structure of the robot was developed. If the assembly process was successful, then it will proceed to algorithm development, which dealing with the computer programming skills. After the algorithm was successfully developed, then it will be implemented in the hardware part for testing its functionality. If the algorithm worked properly, then it will proceed to analysis stage. However, if the algorithm failed to worked properly, then it need to be developed and implemented again to the robot for testing until it was successful.

Figure 3.4 below shows the finalized development of crawler type robot.

Figure 3.4 Finalized development of crawler type robot

Bill of materials (BOM) list is a list that contains the information or details of materials and components used for the project. Table 3.2 shows the BOM list for the crawler type robot project.

Table 3.2 BOM list

Item No.	Description	Material	Quantity
1	Angled bar (25 mm x 25 mm)	Aluminium	3.5 meter
2	Crawler belt (9 mm)	Rubber	2.06 meter
3	PVC sheet (A4 size)	PVC	4 sheets
4	Black tape (48 mm x 9 yards)	-	1 unit
5	Cable tie	Plastic	2 units
6	Screw(8 mm)	Carbon steel	6 units
7	Screw(4 mm)	Aluminium	26 units
8	Washer (10 mm)	Aluminium	2 units
9	Washer (5 mm)	Aluminium	52 units
10	Thread seal tape (5 mm)	-	8 units
11	Bolt nut (8 mm)	Carbon steel	18 units
12	Bolt nut (4 mm)	Aluminium	26 units
13	Multicore wire AWG14 (red)	Copper	0.45 meter
14	Multicore wire AWG14 (black)	Copper	0.45 meter
15	Single core wire (yellow)	Copper	0.3 meter
16	Single core wire (red)	Copper	0.15 meter
17	Single core wire (black)	Copper	0.15 meter
18	SLA Battery 12V (2300mAh)	Lead acid	1 unit
19	Crocodile clips	-	2 units
20	DC geared motor with encoder	-	2 units
21	Dual channel 10A DC motor driver	-	1 unit
22	Enhanced 40 pins PIC start-up kit	-	1 unit
23	PIC16F877A microcontroller	-	1 unit
24	PS2 controller	-	1 unit
25	PS2 controller starter kit	-	1 unit
26	LCD 16x2	-	1 unit
27	Power bank 5V (2200 mAh)	-	1 unit
28	Supporter (25mm)	Wood	0.2 meter
29	Double sided tape (12mm)	-	0.52 meter
30	USB miniB cable (2.0)	-	1 unit

3.1.3. Project Evaluation

Project evaluation is the final phase of this project. In project evaluation phase, the project will be evaluated based on its performance in term of its accuracy and repeatability. The design parameters would be the speed of the robot, while the performance parameters would be the accuracy and repeatability. The methodology used for this research or project was the experiment which consists of lab test and field test. Lab test was conducted on flat surface while field test was conducted on the rough surface. Any other necessary modification will be done if the outcome or result is unsatisfied. Figure 3.5 below describes the flow of project evaluation process.

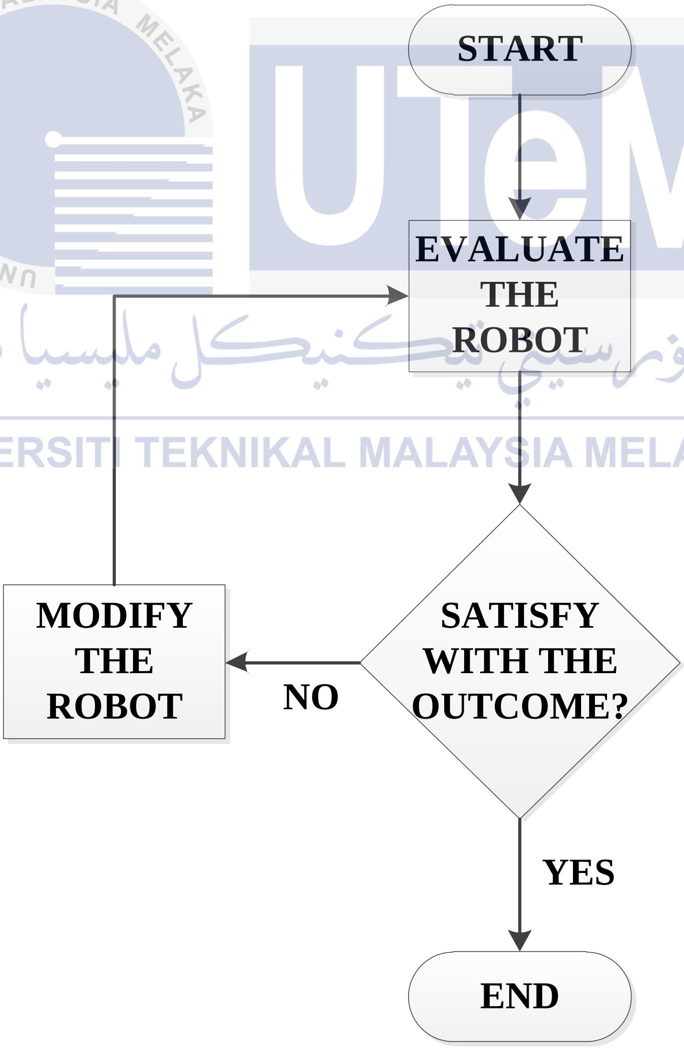


Figure 3.5 Project evaluation flowchart

3.1.4. Project Milestone

Table 3.3 shows the milestone of this project for each phase. This project took nearly two years to finish started with project initialization, then proceed to project development and finally completed at the project evaluation stage.

Table 3.3 Project milestone

Phase	Start	End
1	9th September 2013	31st December 2013
2	1st January 2014	31st April 2014
3	1st May 2014	23rd May 2014

3.1.5. K-Chart

K-Chart is a tool to organize a research systematically in the form of tree diagram. Basically, there are 3 main elements inside the K-Chart: scope, methodology and result. Figure 3.6 shows the K-Chart for this crawler-type robot project. It shows that the scope of robot is narrow down to crawler type robot which operating on land environment only. The lands considered here were only flat and rough surfaces.

Experiment was used as the methodology to carry out the research which consists of lab test and field test. Fabricated robot was used throughout the research. The performance parameters here comprises of accuracy and repeatability which focus more on the crawler belt and motors. However, the design parameter here was the speed of the motors.

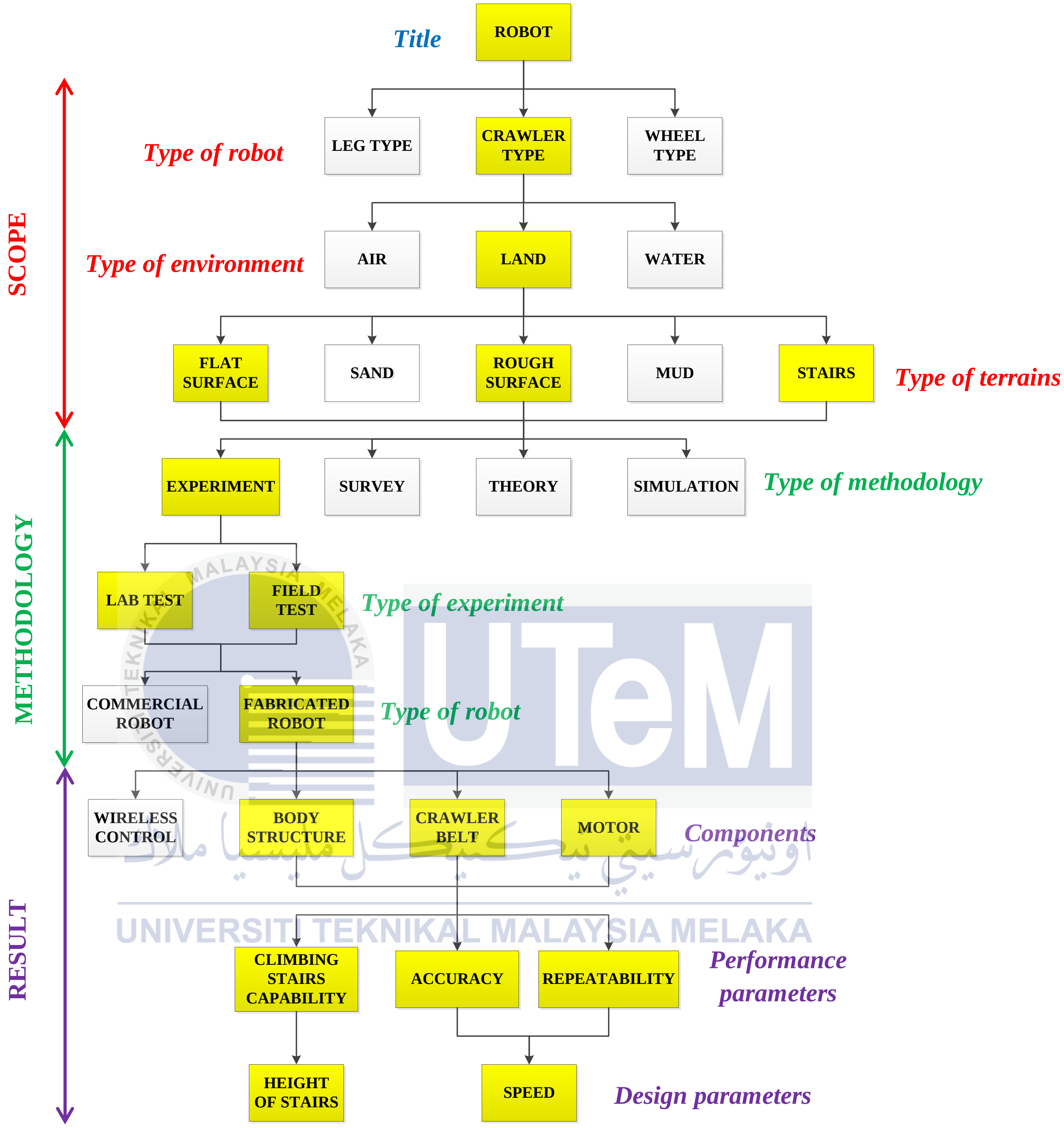


Figure 3.6 K-Chart

3.2. Research Methodology

This part will discuss on the experimental setup and data collection of the project for both lab test and field test.

3.2.1. Lab Test

The objectives of conducting this lab test are to study the relationship between robot’s speed and its accuracy and repeatability on flat surface. Besides that, its goal also to analyze the data collected from the experiment for further improvement.

Part 1: Accuracy and Repeatability Test

The term accuracy can be defined as the extent of data value to the desired value. Higher accuracy indicates that the value is closer to the desired value and vice versa. Accuracy is inversely proportional to the error, which means high accuracy has low error and vice versa. However, the term repeatability can be defined as how frequently the value of data being the same or closer to each other. Therefore, the purpose of this test is to measure the accuracy and repeatability level of the fabricated crawler type robot.

In order to measure the accuracy and repeatability of the robot’s movement, a track or a reference line is needed to perform this test. Therefore, a 6 meter long and 0.325 meter wide yellow line track was setup on the flat surface floor using yellow tape as shown in Figure 3.7. The purpose of using yellow line as the reference line is due to its contrast of the colour. Yellow is the most visible colour from a certain distance if compared to other colours. Therefore, measurement is taken easily from this yellow reference line. Besides that, yellow also served as warning sign. That is why yellow line is widely used in the industries as safety and precaution features.

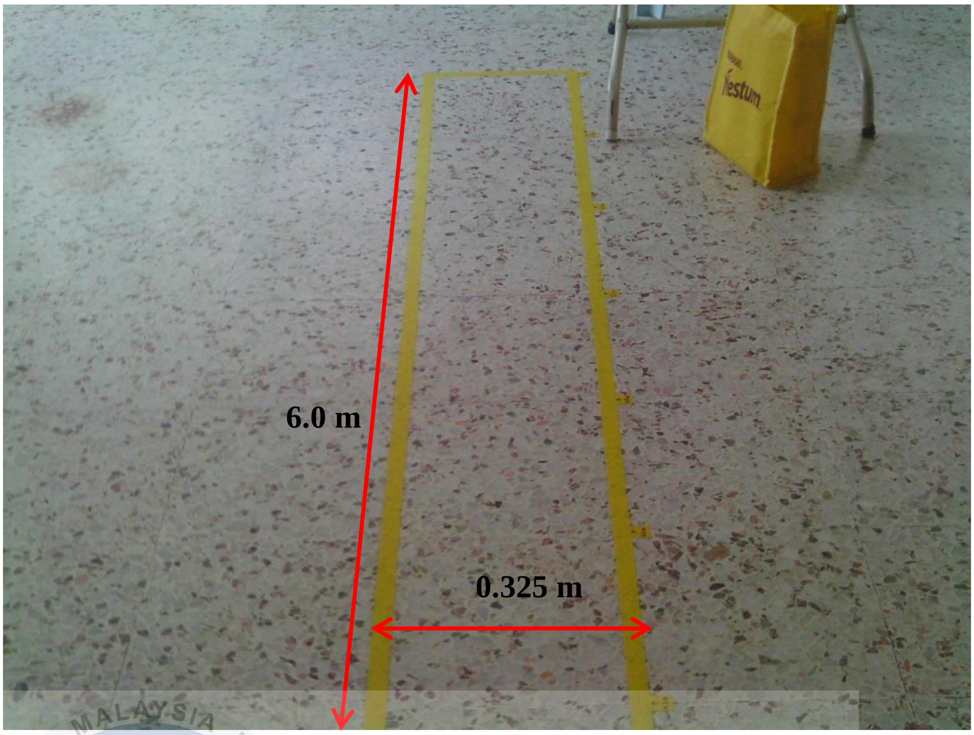


Figure 3.7 Yellow line track

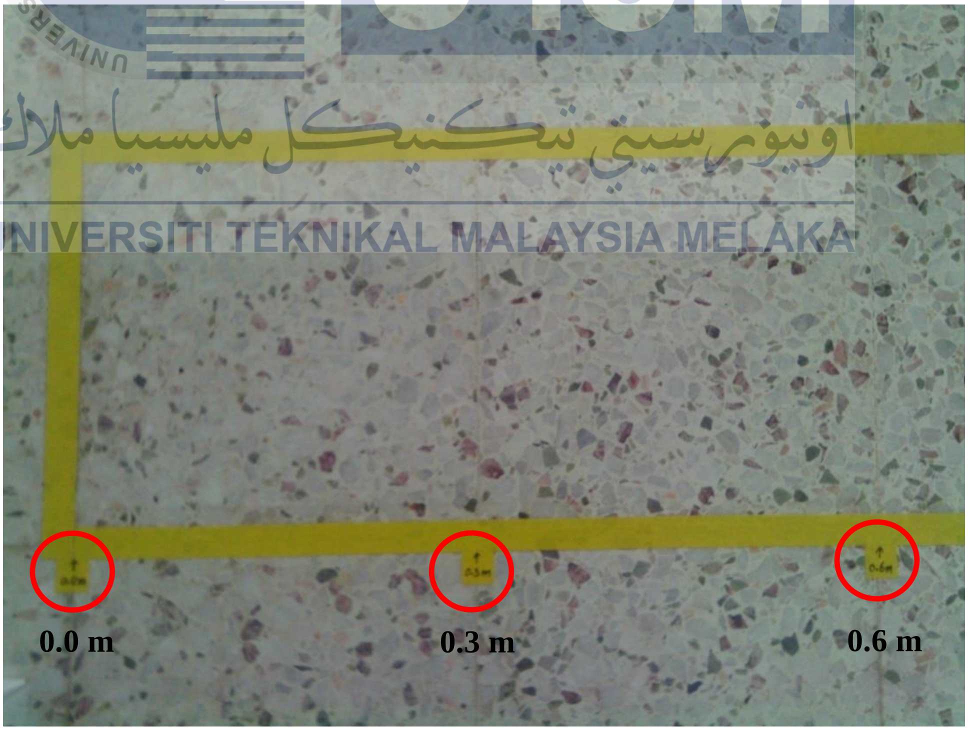


Figure 3.8 Measurement along the yellow line track at the beginning

Then a measurement along one side of the track was written down for every 0.3 meter interval using measuring tape and permanent marker pen as shown in Figure 3.8 and Figure 3.9. In other words, there will be 20 intervals along this yellow line.

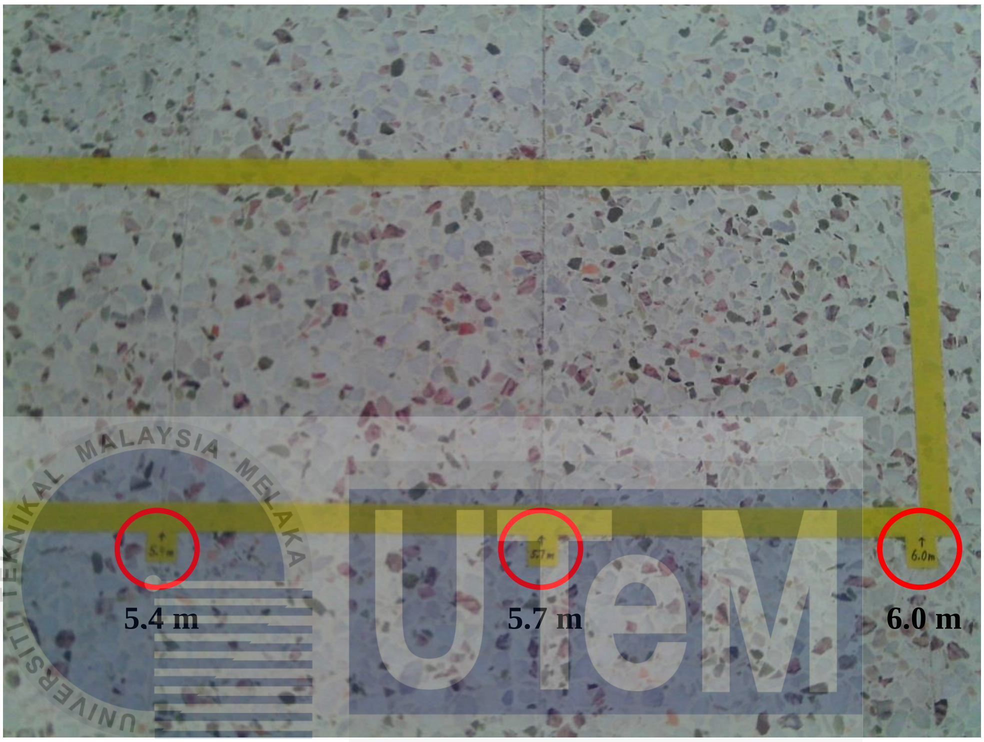


Figure 3.9 Measurement along the yellow line track at the end

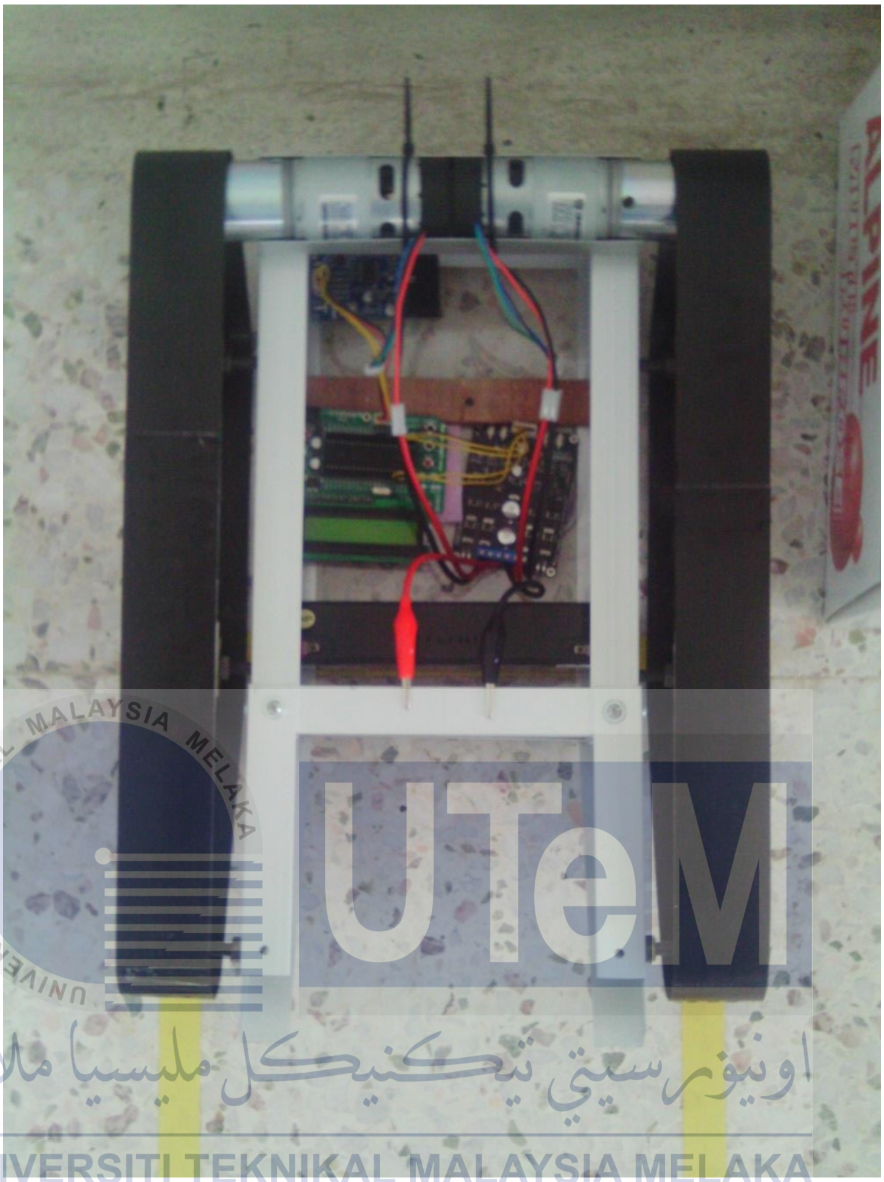


Figure 3.10 Position of crawler type robot at the beginning

Next, the robot was programmed to 25% of robot’s full speed (PWM=64). The crawler type robot was placed on the long yellow line track at starting point (0.0 m) as shown in Figure 3.10.The right hand side of the crawler belt of the robot must be placed in line with the yellow line as shown in Figure 3.11 to calibrate the measurement at the beginning. The purpose of this approach is to eliminate any unwanted error that occurs at the beginning of this experiment.

Figure 3.11 Right hand side of crawler belt in line with yellow line

Finally, the robot was then started to move using PS2 controller and stopped at each 0.3 meter interval until it finished at the end of the track (6.0 m). The deviation of the right hand side crawler belt from the yellow line track was measured using ruler and recorded for every 0.3 meter interval. The indication sign of the errors was given as Figure 3.13 and Figure 3.14.

The above steps were repeated for 3 times to get the average values so the reliability of the data will be higher. After finished with 25% of the robot's full speed, the experiment was continued with 50% (PWM=128), 75% (PWM=192) and 100% (PWM=255) of robot's full speed.

After that, P-controller with different values of Kp was tested to the robot to figure out which value of Kp is most suitable to compensate the error. The speed level of the robot using for this test was 100%. The robot was moved from starting point until the finishing point and the deviation error data was collected to study the relationship between Kp value and the deviation error. The most suitable Kp value will be chosen for the next experiments.

The principle of using P-controller for this robot is shown in Figure 3.12 below.

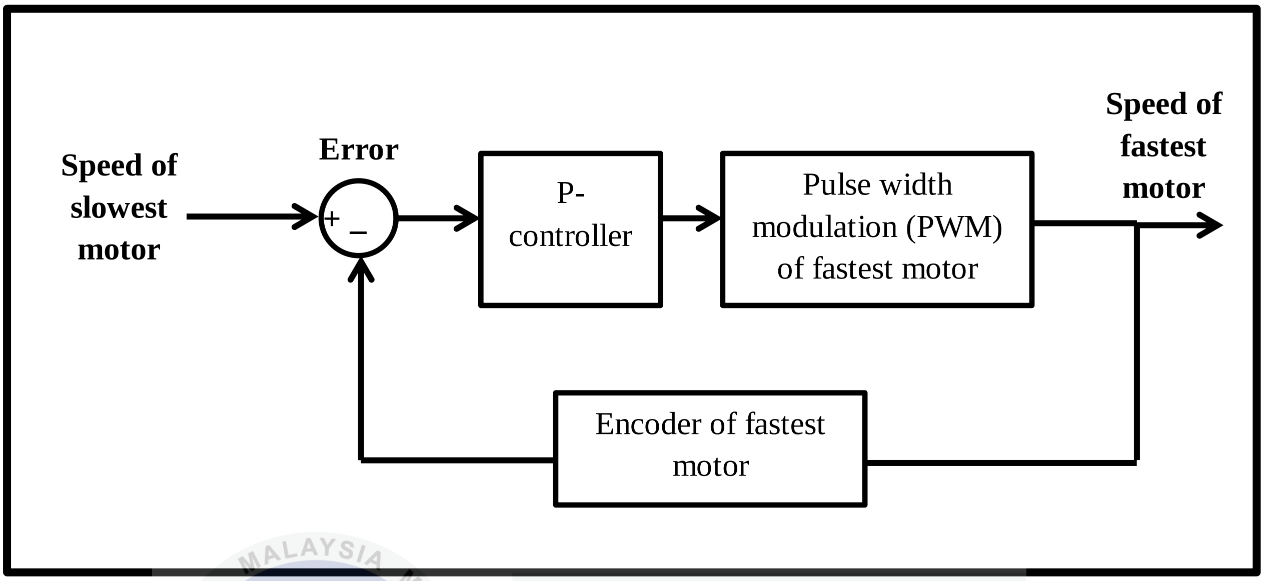


Figure 3.12 Block diagram of P-controller

From this block diagram, the speed of slowest motor would be the desired input or reference value for the system. An encoder could be used to determine or read the speed of the motor. Then the encoder of fastest motor would be read the speed and provide feedback into the system. The difference between the desired value and actual value would be the error for the input of P-controller. The error would be converted to pulse width modulation (PWM) by Kp gain in P-controller. Therefore, a new PWM will be generated to control the speed of the fastest motor. In other words, the fastest motor would be slow down to achieved same speed as the slowest motor.

By using this method, the robot could be achieved better performance in terms of its accuracy and repeatability by moving toward desired direction without deviate too much from its desired route.

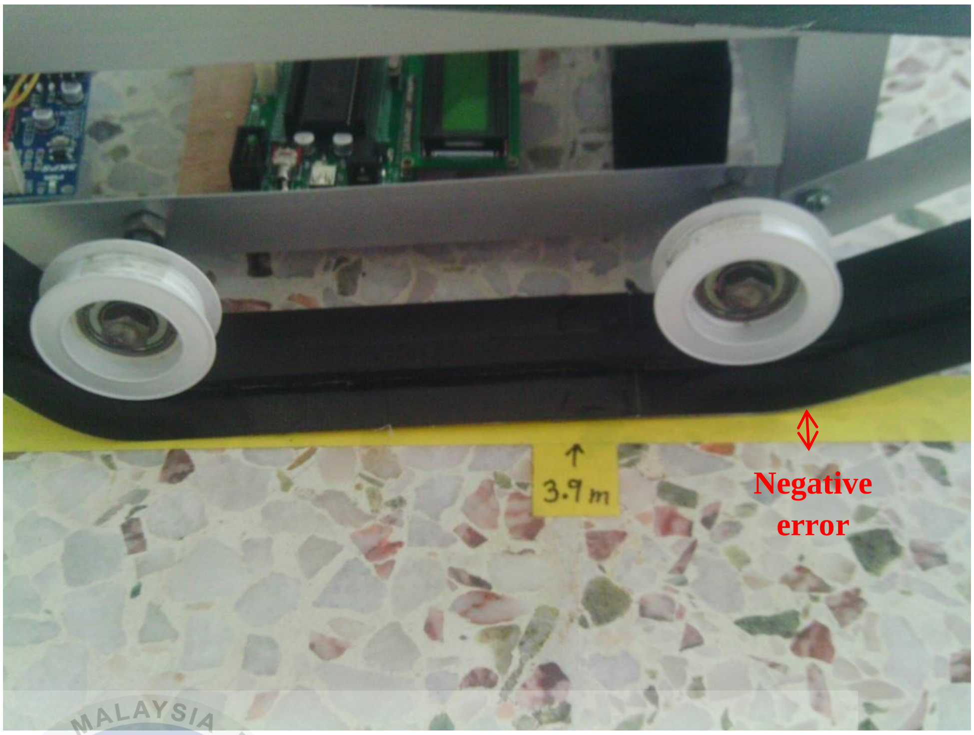


Figure 3.13 Negative error

Figure 3.14 Positive error

Part 2: Climbing Stairs Capability Test

The purpose of this capability test is to measure the ability of the crawler type robot to climb the stairs with different height. Therefore, in order to test its climbing stairs ability, a dummy stairs is required for this testing instead of using the real stairs.

Two dummy stairs (30 cm × 20 cm × 5 cm) which is made of polyfoam as shown in Figure 3.15 were used.

Figure 3.15 Dummy stairs using polyfoam

Then, both the dummy stairs were arranged in line with the yellow line as shown in Figure 3.16 and the distance between these two dummy stairs was assigned to 23 cm as shown in Figure 3.17. The reason of separating these two dummy stairs is due to limitation of the robot’s body structure.

Figure 3.16 Arrangement of dummy stairs

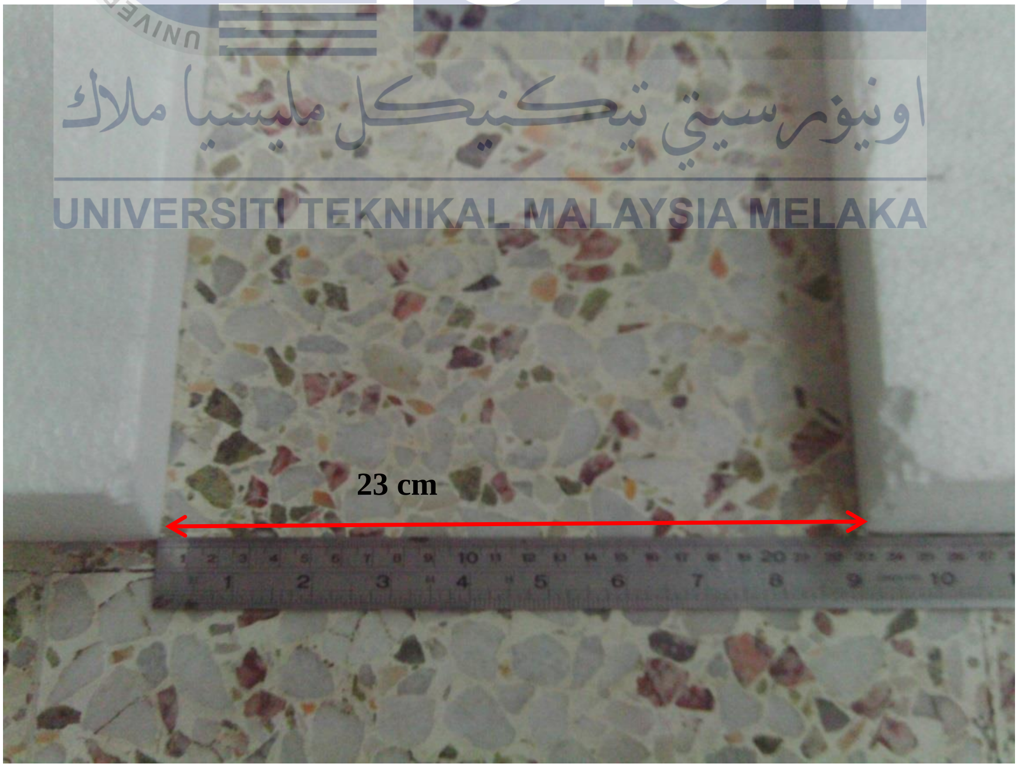


Figure 3.17 Separation of dummy stairs

The design of this crawler type robot was too low, the distance between the floor and the bottom surface of the robot is only 13 mm. Figure 3.18 below shows the distance between robot and floor.

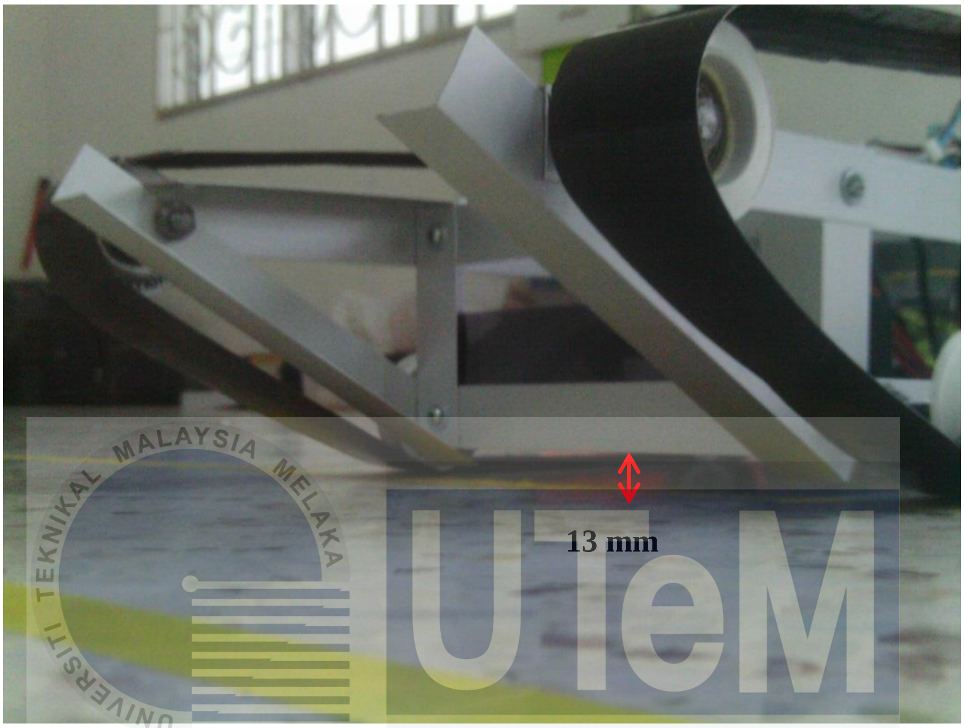


Figure 3.18 Distance between robot and floor

When the robot is trying to climb over the dummy stair, it had been block by the structure of the robot as shown in Figure 3.19. This reason causes the robot hard to lift up and climb over the dummy stairs. Therefore, an alternative method for this experiment mentioned before is needed to replace this type of method.

Figure 3.20 shows the movement of the robot had been stopped by its body structure. Therefore the robot had the difficulty to climb over the stairs easily.

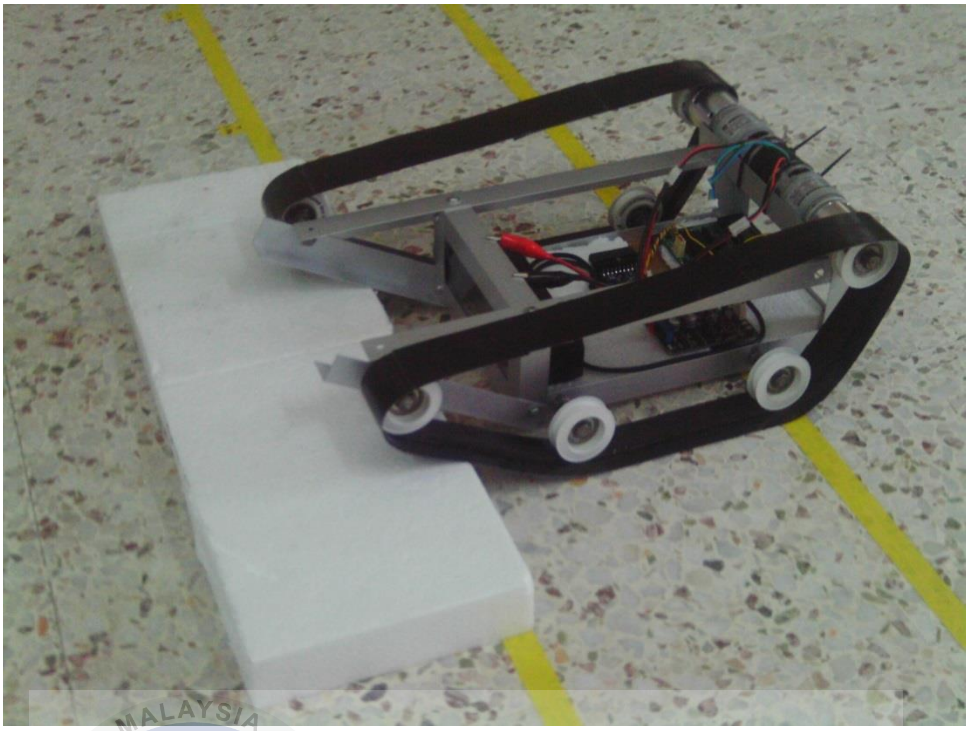


Figure 3.19 Robot climb over the dummy stair

Figure 3.20 Limitation of robot's body structure

Next, the robot was programmed to 100% of its full speed before started the experiment. Then, it was placed before the other yellow line as shown in Figure 3.21 as the initial point.

Figure 3.21 Initial position of the robot

Finally, the robot was then started to move using PS2 controller and stopped after it finished climb down at the end of the stairs. The data was then recorded.

The above steps were repeated for 5 times to get the average values so the reliability of the data will be higher. After that, the experiment was continued with different height of polyfoam dummy stairs (4 cm, 3 cm, 2 cm and 1 cm).

3.2.2. Field Test

The objective of conducting the field test is to study the performance of the fabricated crawler type robot in terms of its accuracy and repeatability on irregular terrain. Besides that, its goal also to analyze the data collected from the experiment for further improvement.

A suitable irregular terrain was found at outdoor as shown in Figure 3.22. The irregular terrains could be the grass, stone or road. But in this case, the grass terrain was chosen and certain area of this irregular terrain which is suitable for this experiment was selected.

Figure 3.22 Irregular terrain

Then the initial point and desired final point was marked on the irregular terrain and the distance between two points was measured using measuring tape as shown in Figure 3.23. The distance between two points was assigned to 1 meter.

Figure 3.23 Initial and final point

Next, the robot was programmed with 100% of robot's full speed (PWM=255) first before conducting the experiment. The fabricated crawler type robot was then placed on the initial point as shown in Figure 3.24 and it was started to move to the desired final point using PS2 controller. The crawler belt of the robot had to be placed in line with the reference line to eliminate unnecessary error at the beginning of the experiment.

After the robot was reached the desired final point, then the deviation error was measured from the reference line using measuring tape and the reading was then recorded. The indication sign of the errors was given as Figure 3.13 and Figure 3.14. The above steps were repeated for 10 times to get the average values so that the reliability of data is higher.

Figure 3.24 Initial position of crawler type robot

3.3. Conclusion

After conducting the experiments mentioned above, the data collected will be analyzed to identify the relationship between the robot’s speed and its accuracy as well as its repeatability. The study of relationship between robot’s speed and accuracy as well as repeatability will then help to improve the performance of the robot in order to move in desired direction on regular and irregular terrains.

Besides that, the data collected will also be analyzed to determine the climbing stairs capability of the robot. Then, the study on its capability will help to improve the performance of the robot in term of its mechanism so that it is able to climb the stairs easily.

CHAPTER 4

RESULTS AND DISCUSSION

This chapter will discuss on the results or data collected during the experiment. Analysis and discussion would also be carried out on the collected data.

4.1. Lab Test

Part 1: Accuracy and Repeatability Test

Lab test was conducted on flat surface terrain where the aim is to identify the performance of the developed robot in term of its accuracy and repeatability.

The accuracy term can be defined as how close a measurement data is closer to the actual value. In other word, high accuracy contributes to low error and vice versa.

While repeatability term can be defined as how close a measurement data is closer to one another. In other word, high repeatability contributes to high stability and vice versa.

Table 4.1 shows the accuracy test results for 25% of robot’s full speed.

Table 4.1 Experimental result on accuracy test for 25% of full speed

Displacement	**Error (*mm*)**			
	1st	**2nd**	**3nd**	**Average**
0.0	0	0	0	0.00
0.3	2	2	-3	0.33
0.6	5	1	-10	-1.33
0.9	3	0	-20	-5.67
1.2	-1	-4	-33	-12.67
1.5	-8	-12	-48	-22.67
1.8	-17	-18	-65	-33.33
2.1	-29	-37	-80	-48.67
2.4	-47	-54	-98	-66.33
2.7	-67	-77	-115	-86.33
3.0	-91	-103	-133	-109.00
3.3	-118	-136	-154	-136.00
3.6	-147	-170	-174	-163.67
3.9	-154	-185	-201	-180.00
4.2	-189	-231	-230	-216.67
4.5	-228	-279	-268	-258.33
4.8	-265	-332	-298	-298.33
5.1	-309	-387	-332	-342.67
5.4	-325	-447	-370	-380.67
5.7	-405	-512	-408	-441.67
6.0	-457	-579	-445	-493.67

Table 4.2 shows the interval error changes for 25% of robot's full speed.

Table 4.2 Interval error changes for 25% of full speed

Displacement	**Error Changes (*mm*)**			
	1st	**2nd**	**3nd**	**Average**
0.0	0	0	0	0.00
0.3	2	2	-3	0.33
0.6	3	-1	-7	-1.67
0.9	-2	-1	-10	-4.33
1.2	-4	-4	-13	-7.00
1.5	-7	-8	-15	-10.00
1.8	-9	-6	-17	-10.67
2.1	-12	-19	-15	-15.33
2.4	-18	-17	-18	-17.67
2.7	-20	-23	-17	-20.00
3.0	-24	-26	-18	-22.67
3.3	-27	-33	-21	-27.00
3.6	-29	-34	-20	-27.67
3.9	-7	-15	-27	-16.33
4.2	-35	-46	-29	-36.67
4.5	-39	-48	-38	-41.67
4.8	-37	-53	-30	-40.00
5.1	-44	-55	-34	-44.33
5.4	-16	-60	-38	-38.00
5.7	-80	-65	-38	-61.00
6.0	-52	-67	-37	-52.00

Figure 4.1 shows the graph of error versus displacement for 25% of robot’s full speed.

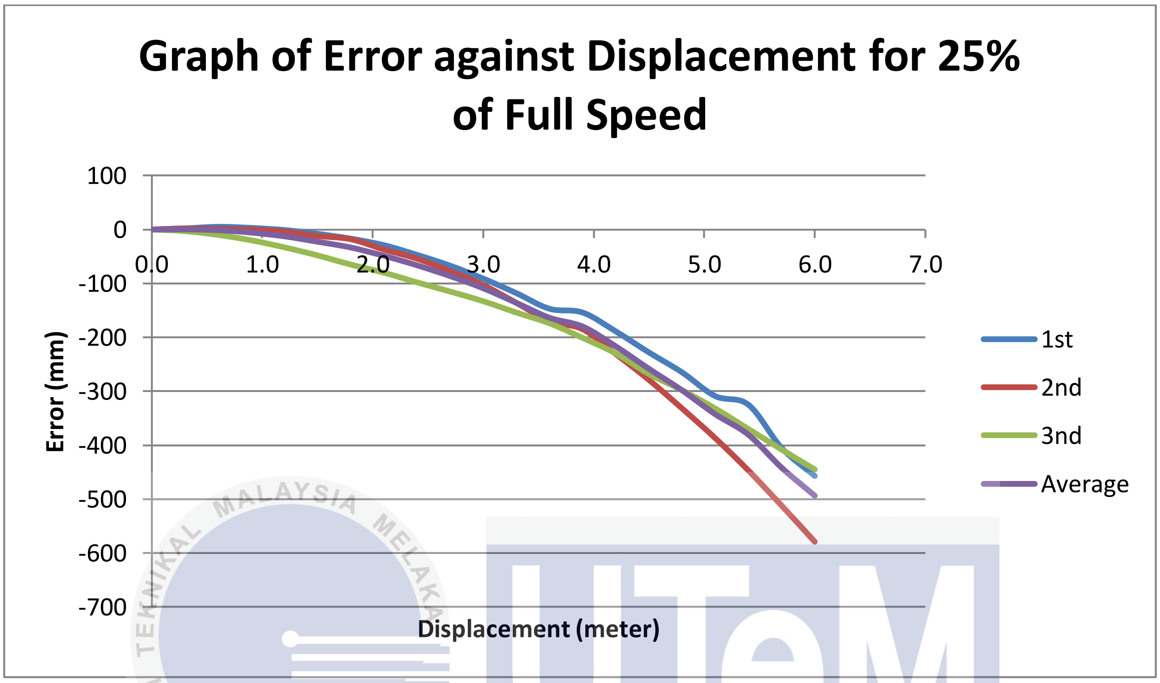


Figure 4.1 Graph of error versus displacement for 25% of full speed

Figure 4.2 shows the graph of error changes versus displacement for 25% of robot's full speed.

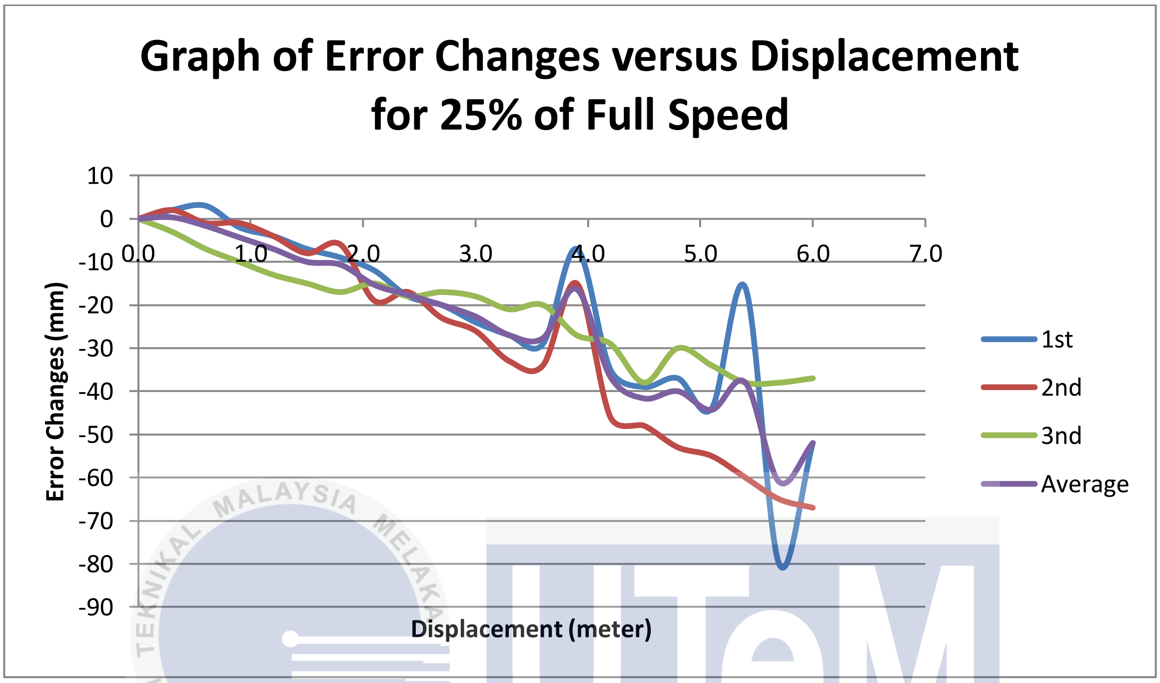


Figure 4.2 Graph of error changes versus displacement for 25% of full speed

Table 4.3 shows the accuracy test results for 25% of robot's full speed.

Table 4.3 Experimental result on accuracy test for 50% of full speed

Displacement	**Error (*mm*)**			
	1st	**2nd**	**3nd**	**Average**
0.0	0	0	0	0.00
0.3	0	-1	-1	-0.67
0.6	-7	-4	-6	-5.67
0.9	-19	-8	-16	-14.33
1.2	-35	-13	-31	-26.33
1.5	-56	-16	-49	-40.33
1.8	-79	-28	-74	-60.33
2.1	-106	-35	-99	-80.00
2.4	-135	-47	-128	-103.33
2.7	-170	-67	-161	-132.67
3.0	-209	-88	-199	-165.33
3.3	-250	-115	-242	-202.33
3.6	-296	-145	-287	-242.67
3.9	-345	-185	-339	-289.67
4.2	-402	-222	-394	-339.33
4.5	-461	-267	-453	-393.67
4.8	-527	-317	-514	-452.67
5.1	-600	-370	-576	-515.33
5.4	-670	-425	-635	-576.67
5.7	-751	-487	-696	-644.67
6.0	-836	-551	-758	-715.00

Table 4.4 shows the interval error changes for 50% of robot’s full speed.

Table 4.4 Interval error changes for 50% of full speed

Displacement	Error Changes (*mm*)			
	1st	2nd	3nd	Average
0.0	0	0	0	0.00
0.3	0	-1	-1	-0.67
0.6	-7	-3	-5	-5.00
0.9	-12	-4	-10	-8.67
1.2	-16	-5	-15	-12.00
1.5	-21	-3	-18	-14.00
1.8	-23	-12	-25	-20.00
2.1	-27	-7	-25	-19.67
2.4	-29	-12	-29	-23.33
2.7	-35	-20	-33	-29.33
3.0	-39	-21	-38	-32.67
3.3	-41	-27	-43	-37.00
3.6	-46	-30	-45	-40.33
3.9	-49	-40	-52	-47.00
4.2	-57	-37	-55	-49.67
4.5	-59	-45	-59	-54.33
4.8	-66	-50	-61	-59.00
5.1	-73	-53	-62	-62.67
5.4	-70	-55	-59	-61.33
5.7	-81	-62	-61	-68.00
6.0	-85	-64	-62	-70.33

Figure 4.3 shows the graph of error versus displacement for 50% of robot's full speed.

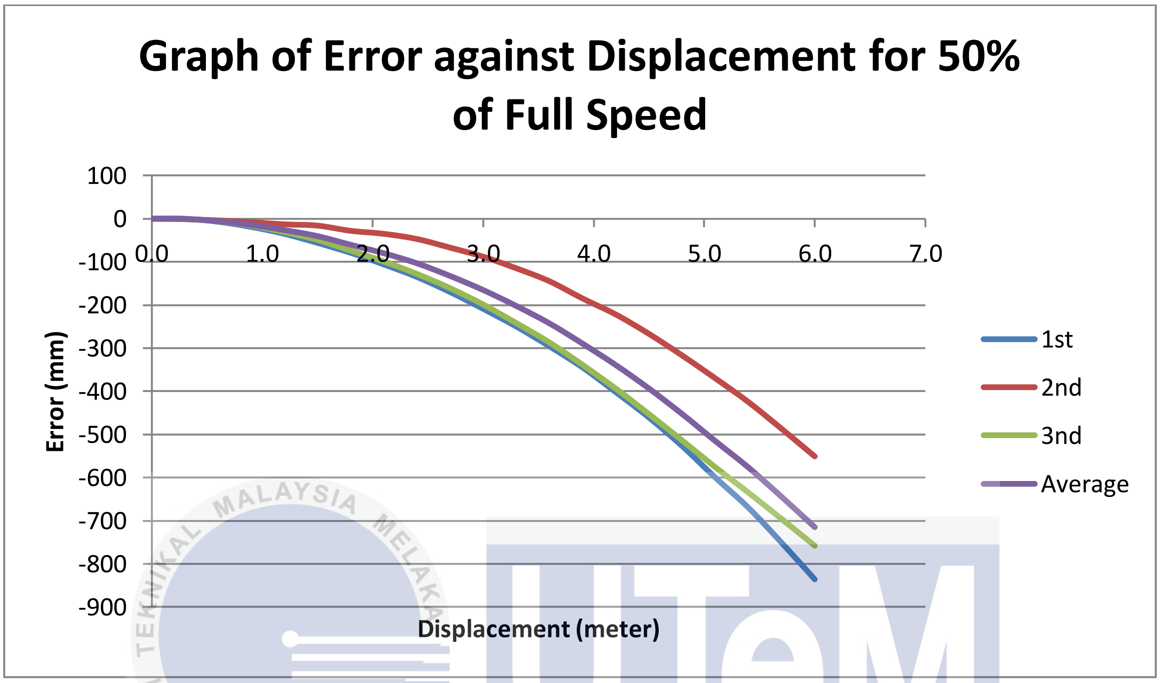


Figure 4.3 Graph of error versus displacement for 50% of full speed

Figure 4.4 shows the graph of error changes versus displacement for 50% of robot’s full speed.

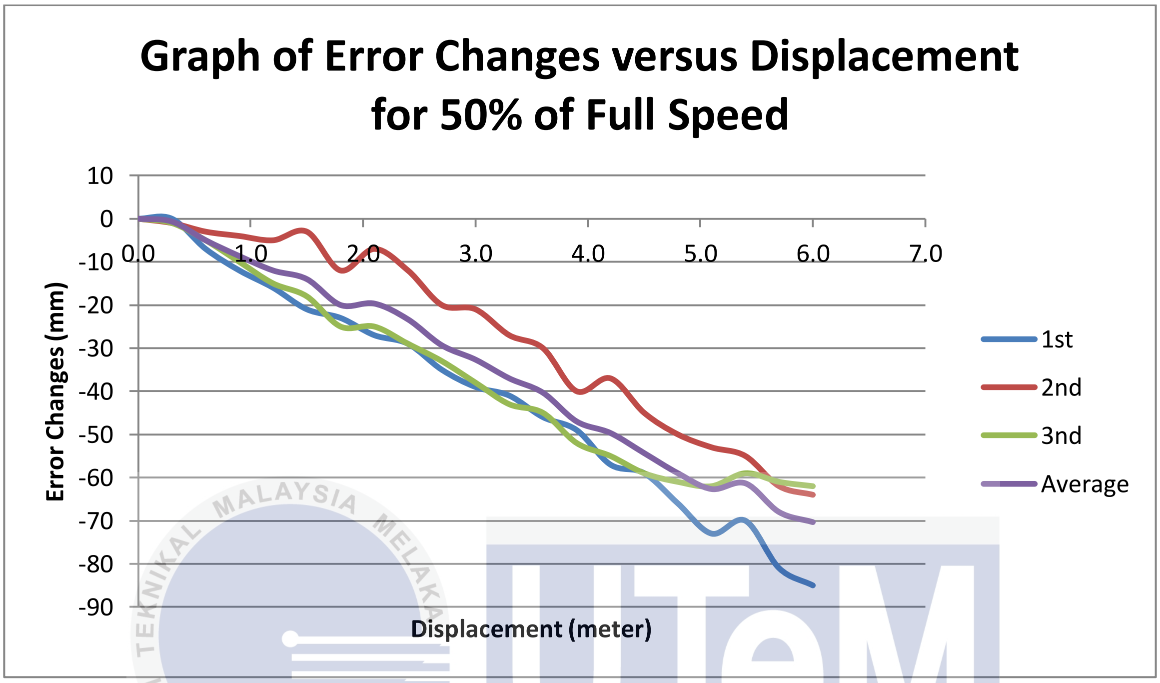


Figure 4.4 Graph of error changes versus displacement for 50% of full speed

Table 4.5 shows the accuracy test results for 75% of robot’s full speed.

Table 4.5 Experimental result on accuracy test for 75% of full speed

Displacement	**Error (*mm*)**			
	1st	**2nd**	**3nd**	**Average**
0.0	0	0	0	0.00
0.3	1	1	2	1.33
0.6	2	-1	-1	0.00
0.9	1	-6	-6	-3.67
1.2	-3	-5	-11	-6.33
1.5	-9	-7	-19	-11.67
1.8	-18	-12	-30	-20.00
2.1	-26	-18	-42	-28.67
2.4	-37	-30	-54	-40.33
2.7	-51	-43	-64	-52.67
3.0	-63	-60	-76	-66.33
3.3	-78	-78	-86	-80.67
3.6	-88	-82	-100	-90.00
3.9	-103	-91	-114	-102.67
4.2	-119	-105	-134	-119.33
4.5	-139	-125	-156	-140.00
4.8	-161	-149	-180	-163.33
5.1	-185	-174	-215	-191.33
5.4	-201	-199	-220	-206.67
5.7	-227	-223	-240	-230.00
6.0	-248	-250	-262	-253.33

Table 4.6 shows the interval error changes for 75% of robot's full speed.

Table 4.6 Interval error changes for 75% of full speed

Displacement	**Error Changes (*mm*)**			
	1st	**2nd**	**3nd**	**Average**
0.0	0	0	0	0.00
0.3	1	1	2	1.33
0.6	1	-2	-3	-1.33
0.9	-1	-5	-5	-3.67
1.2	-4	1	-5	-2.67
1.5	-6	-2	-8	-5.33
1.8	-9	-5	-11	-8.33
2.1	-8	-6	-12	-8.67
2.4	-11	-12	-12	-11.67
2.7	-14	-13	-10	-12.33
3.0	-12	-17	-12	-13.67
3.3	-15	-18	-10	-14.33
3.6	-10	-4	-14	-9.33
3.9	-15	-9	-14	-12.67
4.2	-16	-14	-20	-16.67
4.5	-20	-20	-22	-20.67
4.8	-22	-24	-24	-23.33
5.1	-24	-25	-35	-28.00
5.4	-16	-25	-5	-15.33
5.7	-26	-24	-20	-23.33
6.0	-21	-27	-22	-23.33

Figure 4.5 shows the graph of error versus displacement for 75% of robot's full speed.

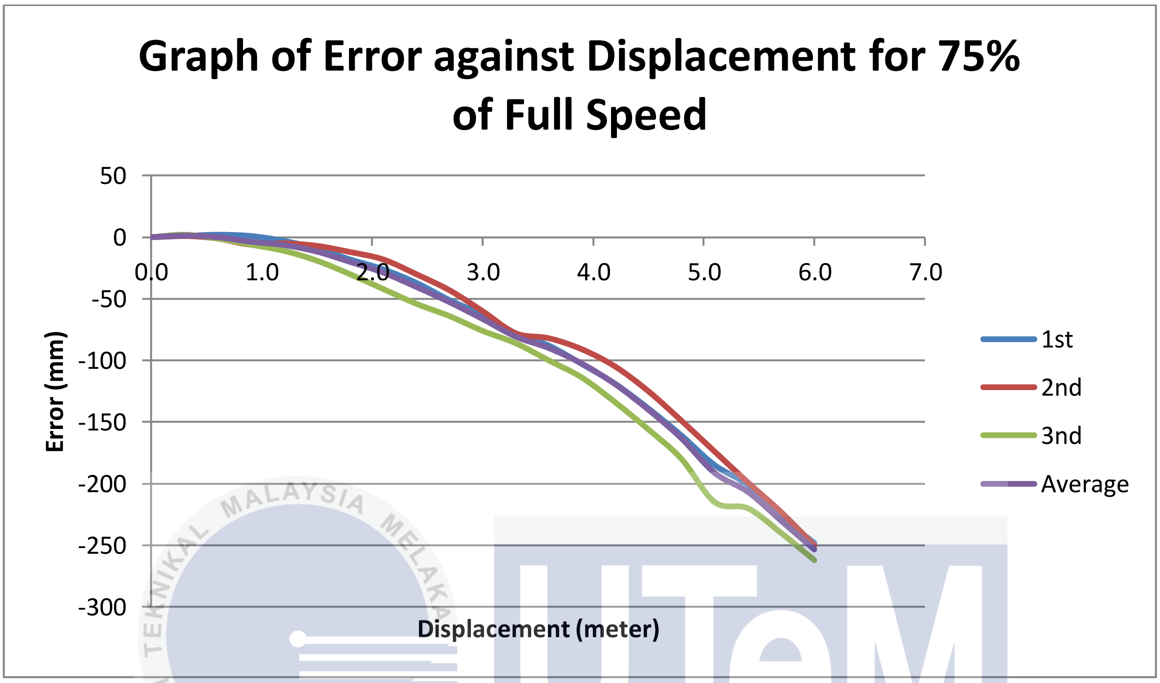


Figure 4.5 Graph of error versus displacement for 75% of full speed

Figure 4.6 shows the graph of error changes versus displacement for 75% of robot's full speed.

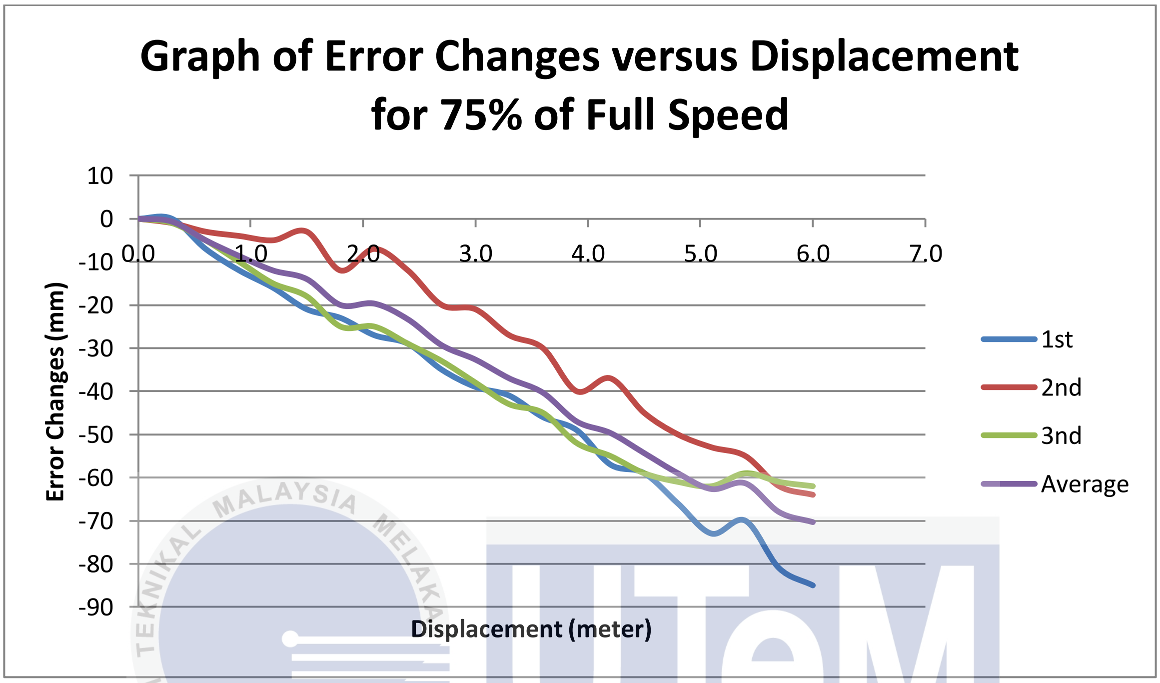


Figure 4.6 Graph of error changes versus displacement for 75% of full speed

Table 4.7 shows the accuracy test results for 100% of robot’s full speed.

Table 4.7 Experimental result on accuracy test for 100% of full speed

Displacement	**Error (*mm*)**			
	1st	**2nd**	**3nd**	**Average**
0.0	0	0	0	0.00
0.3	-1	-2	0	-1.00
0.6	2	-6	0	-1.33
0.9	4	-9	-2	-2.33
1.2	2	-15	-4	-5.67
1.5	0	-28	-8	-12.00
1.8	-6	-29	-11	-15.33
2.1	-15	-35	-17	-22.33
2.4	-26	-45	-26	-32.33
2.7	-38	-52	-40	-43.33
3.0	-52	-62	-53	-55.67
3.3	-66	-77	-66	-69.67
3.6	-75	-90	-79	-81.33
3.9	-86	-102	-92	-93.33
4.2	-99	-119	-109	-109.00
4.5	-113	-134	-128	-125.00
4.8	-123	-147	-152	-140.67
5.1	-134	-165	-175	-158.00
5.4	-146	-183	-197	-175.33
5.7	-155	-203	-223	-193.67
6.0	-166	-220	-245	-210.33

Table 4.8 shows the interval error changes for 100% of robot's full speed.

Table 4.8 Interval error changes for 100% of full speed

Displacement	**Error Changes (*mm*)**			
	1st	**2nd**	**3nd**	**Average**
0.0	0	0	0	0.00
0.3	-1	-2	0	-1.00
0.6	3	-4	0	-0.33
0.9	2	-3	-2	-1.00
1.2	-2	-6	-2	-3.33
1.5	-2	-13	-4	-6.33
1.8	-6	-1	-3	-3.33
2.1	-9	-6	-6	-7.00
2.4	-11	-10	-9	-10.00
2.7	-12	-7	-14	-11.00
3.0	-14	-10	-13	-12.33
3.3	-14	-15	-13	-14.00
3.6	-9	-13	-13	-11.67
3.9	-11	-12	-13	-12.00
4.2	-13	-17	-17	-15.67
4.5	-14	-15	-19	-16.00
4.8	-10	-13	-24	-15.67
5.1	-11	-18	-23	-17.33
5.4	-12	-18	-22	-17.33
5.7	-9	-20	-26	-18.33
6.0	-11	-17	-22	-16.67

Figure 4.7 shows the graph of error versus displacement for 100% of robot's full speed.

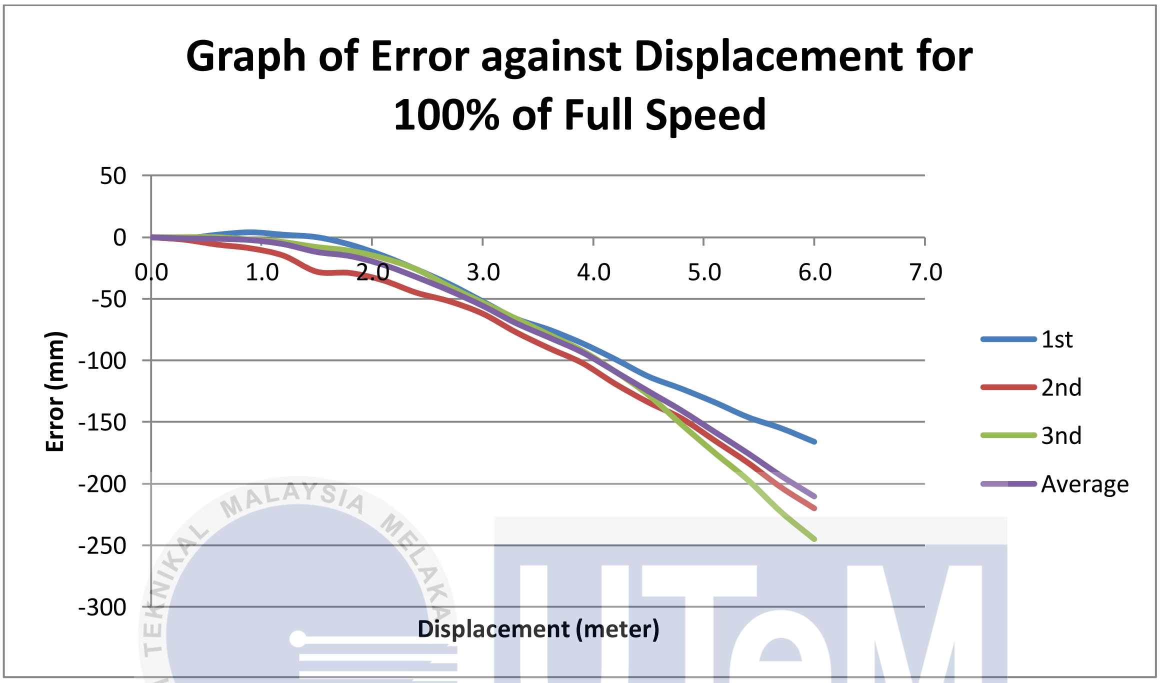


Figure 4.7 Graph of error versus displacement for 100% of full speed

Figure 4.8 shows the graph of error changes versus displacement for 100% of robot's full speed.

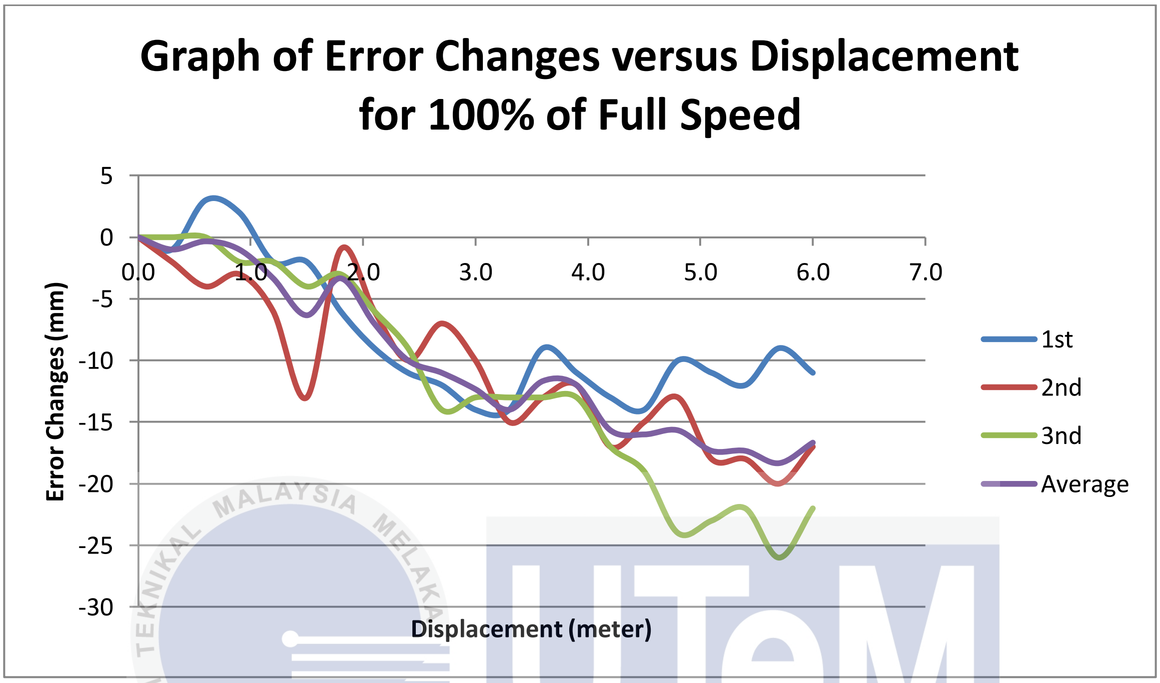


Figure 4.8 Graph of error changes versus displacement for 100% of full speed

Table 4.9 shows the accuracy test results for different level of robot’s full speed.

Table 4.9 Experimental result on accuracy test for different level of robot’s full speed

Displacement	**Error (*mm*)**			
	25%	**50%**	**75%**	**100%**
0.0	0.00	0.00	0.00	0.00
0.3	0.33	-0.67	1.33	-1.00
0.6	-1.33	-5.67	0.00	-1.33
0.9	-5.67	-14.33	-3.67	-2.33
1.2	-12.67	-26.33	-6.33	-5.67
1.5	-22.67	-40.33	-11.67	-12.00
1.8	-33.33	-60.33	-20.00	-15.33
2.1	-48.67	-80.00	-28.67	-22.33
2.4	-66.33	-103.33	-40.33	-32.33
2.7	-86.33	-132.67	-52.67	-43.33
3.0	-109.00	-165.33	-66.33	-55.67
3.3	-136.00	-202.33	-80.67	-69.67
3.6	-163.67	-242.67	-90.00	-81.33
3.9	-180.00	-289.67	-102.67	-93.33
4.2	-216.67	-339.33	-119.33	-109.00
4.5	-258.33	-393.67	-140.00	-125.00
4.8	-298.33	-452.67	-163.33	-140.67
5.1	-342.67	-515.33	-191.33	-158.00
5.4	-380.67	-576.67	-206.67	-175.33
5.7	-441.67	-644.67	-230.00	-193.67
6.0	-493.67	-715.00	-253.33	-210.33

Table 4.10 shows the interval error changes for different level of robot’s full speed.

Table 4.10 Interval error changes for different level of robot’s full speed

Displacement	**Error Changes (*mm*)**			
	25%	**50%**	**75%**	**100%**
0.0	0.00	0.00	0.00	0.00
0.3	0.33	-0.67	1.33	-1.00
0.6	-1.66	-5.00	-1.33	-0.33
0.9	-4.34	-8.66	-3.67	-1.00
1.2	-7.00	-12.00	-2.66	-3.34
1.5	-10.00	-14.00	-5.34	-6.33
1.8	-10.66	-20.00	-8.33	-3.33
2.1	-15.34	-19.67	-8.67	-7.00
2.4	-17.66	-23.33	-11.66	-10.00
2.7	-20.00	-29.34	-12.34	-11.00
3.0	-22.67	-32.66	-13.66	-12.34
3.3	-27.00	-37.00	-14.34	-14.00
3.6	-27.67	-40.34	-9.33	-11.66
3.9	-16.33	-47.00	-12.67	-12.00
4.2	-36.67	-49.66	-16.66	-15.67
4.5	-41.66	-54.34	-20.67	-16.00
4.8	-40.00	-59.00	-23.33	-15.67
5.1	-44.34	-62.66	-28.00	-17.33
5.4	-38.00	-61.34	-15.34	-17.33
5.7	-61.00	-68.00	-23.33	-18.34
6.0	-52.00	-70.33	-23.33	-16.66

Figure 4.9 shows the graph of error versus displacement for different level of robot's full speed.

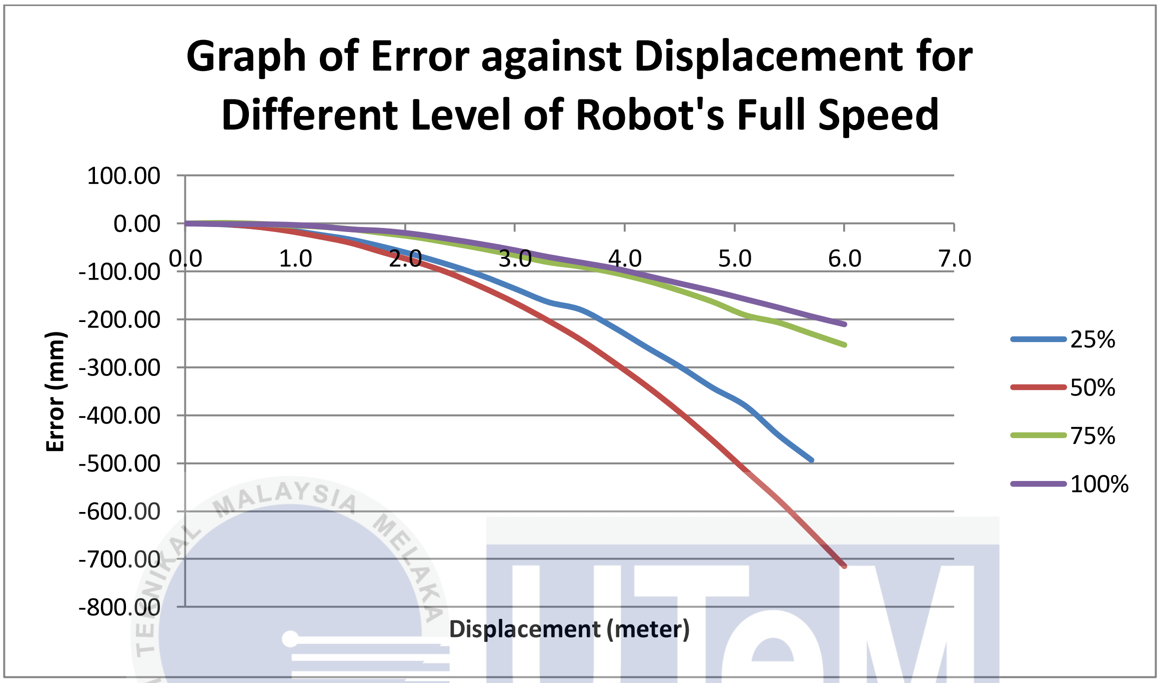


Figure 4.9 Graph of error versus displacement for different level of robot's full speed

Figure 4.10 shows the graph of error changes versus displacement for different level of robot's full speed.

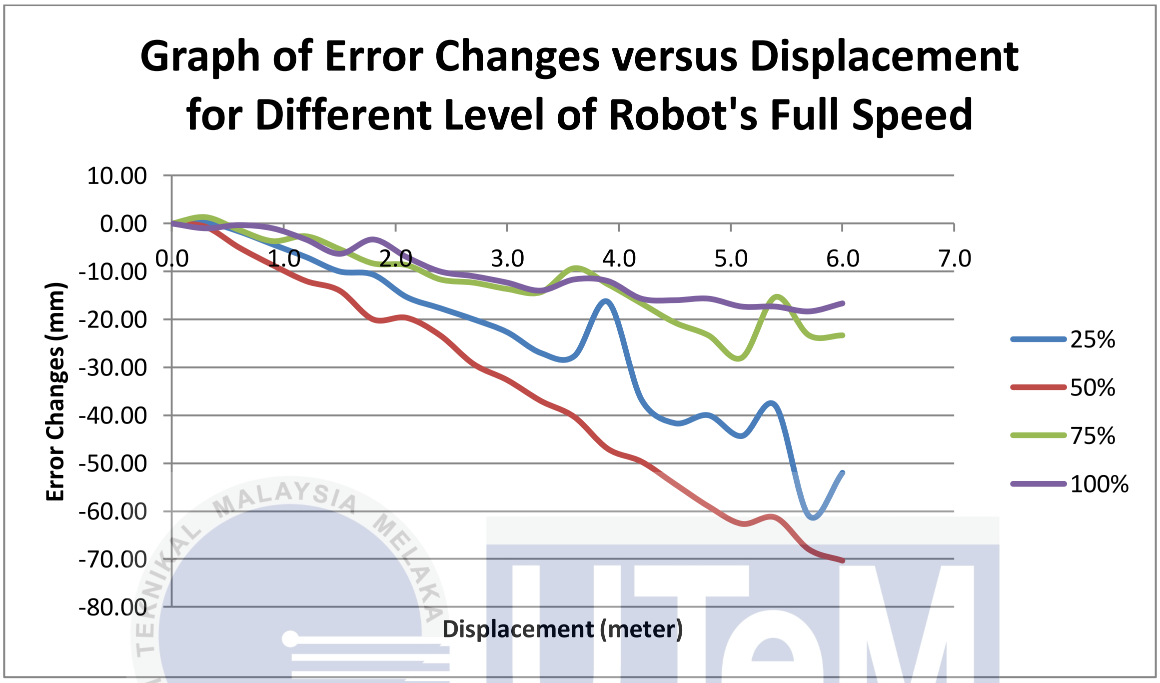


Figure 4.10 Graph of error changes versus displacement for different level of robot's full speed

Table 4.11 shows the accuracy test results for 100% of robot's full speed with P-controller.

Table 4.11 Experimental result on accuracy test for 100% of full speed with P-controller

Kp	**Error (*mm*)**			
	1st	**2nd**	**3nd**	**Average**
0.1	-146	-193	-215	-184.67
0.2	-126	-166	-184	-158.67
0.3	-105	-138	-154	-132.33
0.4	-85	-111	-124	-106.67
0.5	-65	-84	-94	-81.00
0.6	-45	-57	-63	-55.00
0.7	-25	-30	-33	-29.33
0.8	-4	-3	-3	-3.33
0.9	16	25	27	22.67
1.0	36	52	58	48.67

Figure 4.11 shows the graph of error versus Kp value for 100% of robot’s full speed with P-controller.

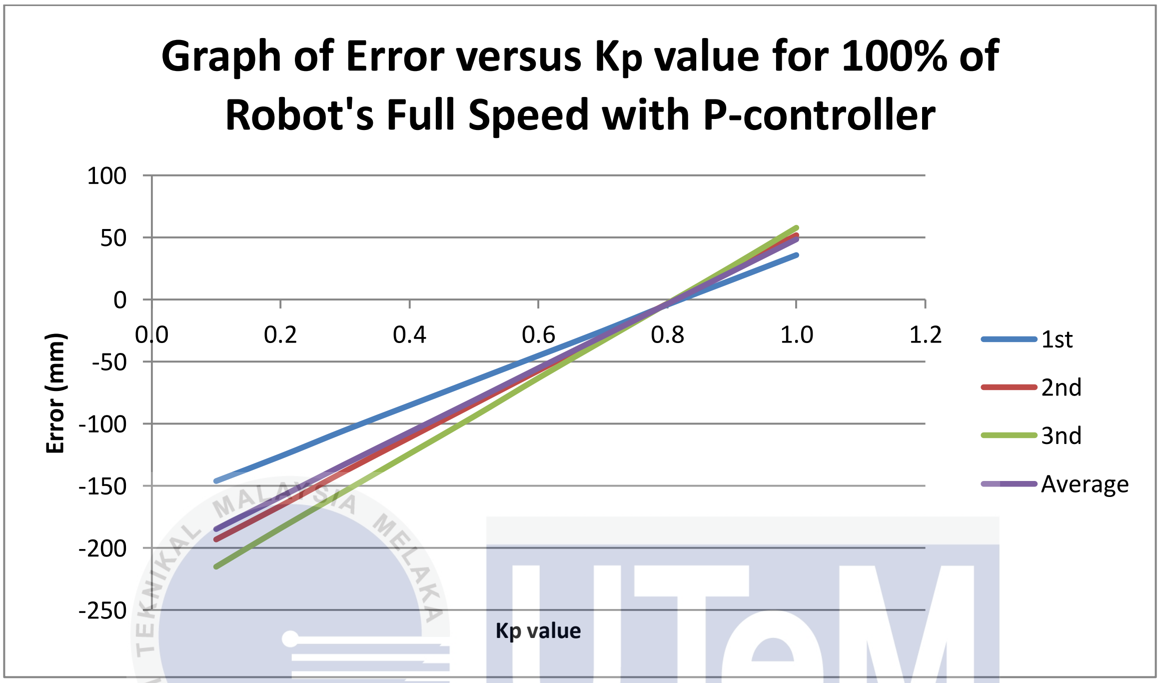


Figure 4.11 Graph of error versus Kp value for 100% of robot’s full speed with P-controller

Part 2: Climbing Stairs Capability Test

This test was conducted where the aim is to identify the performance of the developed robot in term of its climbing stairs capability. The performance parameter of this test was the robot’s capability while the design parameter was the height of stairs.

Table 4.12 shows the result of the climbing stairs capability test.

Table 4.12 Climbing stairs capability test result

Height of Stairs (cm)	**Trials**				
	1st	**2nd**	**3rd**	**4th**	**5th**
1	√	√	√	√	√
2	√	√	√	√	√
3	×	√	√	√	√
4	×	×	×	×	×
5	×	×	×	×	×

Symbols indication

√ = Succeed

× = Failed

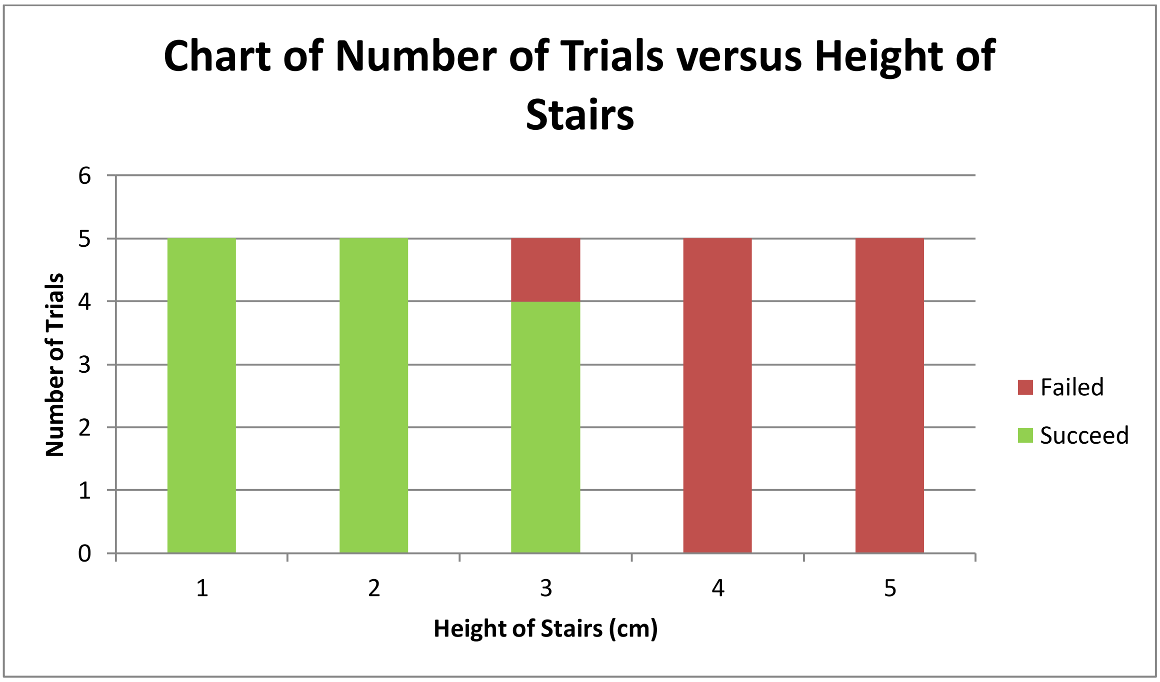


Figure 4.12 Chart of number of trials versus height of stairs

Figure 4.12 shows the chart of trials versus height of stairs. There are five trials for different level of height of stairs. Green colour represents the number of success while red colour represents the number of failure. The analysis of this capability test will be discussed on the next part.

4.2. Field Test

Field test was conducted in this project to determine the performance of the crawler type robot on rough surface or irregular terrain in term of its accuracy and repeatability. Table 4.13 shows the data collected for this field test and Figure 4.13 shows the graph of error versus trials.

Table 4.13 Field test result

Trials	Error (mm)
1	-134
2	-98
3	-94
4	-153
5	-32
6	12
7	-56
8	-43
9	-77
10	14

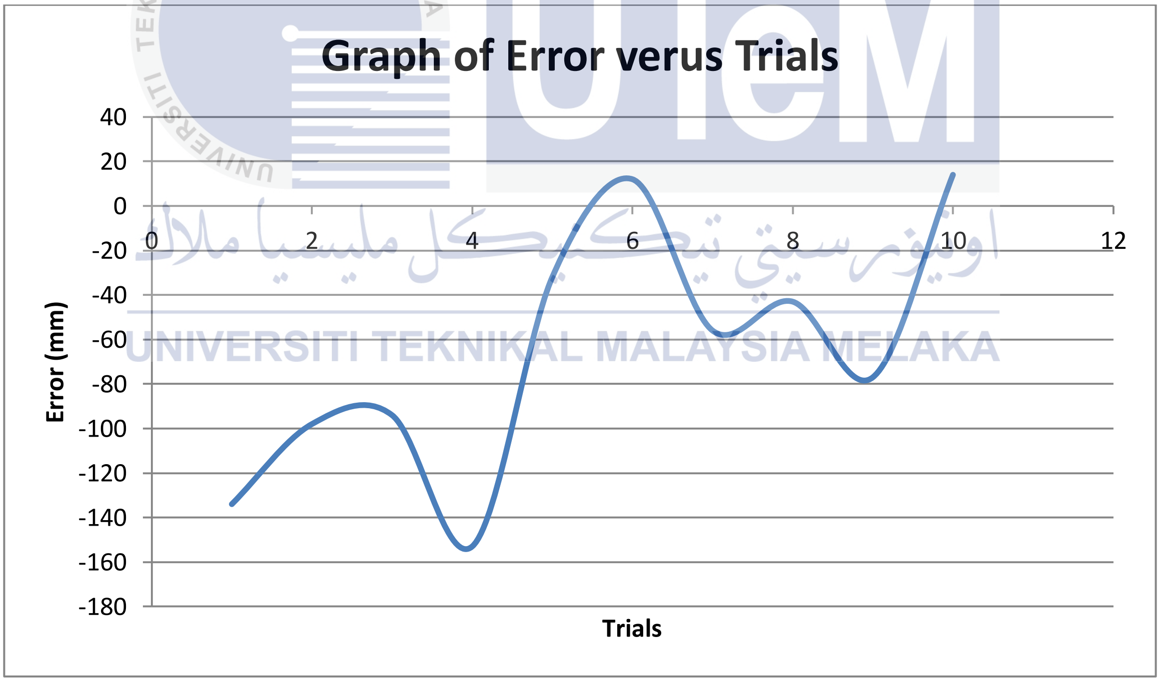


Figure 4.13 Graph of error versus trials

4.3. Analysis of Information

Lab test

From the findings given from Figure 4.9, it shows the deviation error of the robot's movement is inversely proportional to the speed of robot. In other words, the lower speed will contribute to greater deviation error. Besides that, other findings show most of the deviation errors are skewed to negative side, which mean the robot are moving more to the left hand side even though it was programmed to move straight forward.

Figure 4.9 shows the graph of error against displacement for different level of robot's full speed. Based on this finding, the mean of the data for each level of robot's full speed are -164.87 mm (25%), -250.05 mm (50%), -90.28 mm (75%) and -77.38 mm (100%). However, the standard deviation of the data for each level of robot's full speed are 156.57 mm (25%), 229.58 mm (50%), 82.48 mm (75%) and 69.62 mm (100%).

In other word, 100% of robot's full speed contributes higher accuracy and repeatability compared to lower level of robot's full speed.

Besides that, Figure 4.10 shows the graph of error changes versus displacement for different level of robot's full speed. Based on this finding, the peak values for each level of robot's full speed are -61.00 mm (25%), -70.33 mm (50%), -28.00 mm (75%) and -18.34 mm (100%). However, the minimum values for each level of robot's full speed are given 0.33 mm (25%), -0.67 mm (50%), ±1.33 mm (75%) and -0.33 mm (100%).

Figure 4.11 shows the graph of error versus Kp value for 100% of robot's full speed with P-controller. From this finding, the negative deviation error was gradually decreased when the Kp gain was increased up to 0.8 value of Kp. Beyond this value could increase the positive deviation error. Among these 10 Kp gains, 0.8 is the most suitable value to implement inside the P-controller since it has the smallest deviation error with the average of -3.33 mm.

From the findings given in Figure 4.12, all the number of trials for climbing the 1 cm and 2 cm stairs were successful. However, only 80% of the trials were succeed for climbing 3 cm stairs. Lastly, there were 100% of failures in 4 cm and 5 cm stairs.

This statistic shows the robot was only capable to climb over the dummy stairs up to 3 cm. The robot was not able to climb over the dummy stairs beyond than 3 cm due to its limitation of body structure that had mentioned before in Figures 3.18, 3.19 and 3.20.

Since the distance of the robot and the ground or floor is only 13 mm, so it cannot be lifted too steep, else the behind part of the robot will touch the ground and this will prevent the robot to lift up more. Besides that, the tension of the crawler belt was not enough high to grip the stairs and climb over it.

Field test

From the findings illustrated in Figure 4.13, it shows the movement of the robot was not so consistent on irregular terrain. The average value or mean of the data was given -66.10 mm while its standard deviation was 56.17 mm. However, the peak value of the data collected was -153 mm while the minimum deviation error was 12 mm.

The reason of large deviation error on irregular terrain compared to regular terrain was the uneven surface of irregular terrain which causing the robot hard to move in one direction consistently. Even it was equipped with P-controller, but it still deviate from the desired route.

When a robot moves on an irregular terrain, there are many factors need to be considered in order to make the robot move in desired route. One of the factors could be the friction force between the rough surface and the crawler belt. Besides that, the design of this robot was too low, so the friction force not only acting on the crawler belt, but also the beneath surface of the robot. Therefore, the grass drags the movement of the robot and affects the overall performance in terms of its accuracy and repeatability too.

4.4. Synthesis of Information

Link

A mathematical equation could be developed from the Figure 4.5 finding above:

$$\mathit{Deviation\ error} \propto \frac{1}{\mathit{Robot's\ speed}} \tag{4.1}$$

$$e = \frac{k}{v} \tag{4.2}$$

where

e = deviation error (m).

v = linear velocity (m/s).

k = constant (m^2/s).

Difference

The difference of the uncompensated system and P-controller system is based on the deviation error. The deviation error of P-controller is much smaller than the uncompensated system. The uncompensated system has the largest deviation error compared to the P-controller system. Besides that, the standard deviation of the P-controller is smaller than the uncompensated system too. In other words, P-controller system has higher accuracy and repeatability.

Trade off

Table 4.14 Advantages and disadvantages of method

Method	Advantages	Disadvantages
Uncompensated	• Simple programming	• Large deviation error • Less accurate • Large standard deviation • Low repeatability
P-controller	• Small deviation error • Highly accurate • Small standard deviation • High repeatability	• Complex programming

4.5. Evaluation of Information

Due to large deviation error of uncompensated system, P-controller is chosen or preferred to implement into the crawler type robot. However, implementation of P-controller would be more complex if compared to uncompensated system. In order to improve the accuracy and repeatability, P-controller system was preferable.

4.6. SWOT Analysis

SWOT is a powerful analysis tool for evaluating the strengths, weaknesses, opportunities and threats of the project or research. Table 4.15 shows the SWOT analysis done on the fabricated crawler type robot.

Table 4.15 SWOT analysis of fabricated robot

Strengths	**Weaknesses**
• Stable due to its low centre of gravity. • Could be controlled wirelessly. • Low cost.	• Cannot climb over the stairs with height more than 3 cm. • Large deviation error without compensated system.
Opportunities	**Threats**
• PID-controller could be used to implement in this robot. • The body structure of the robot could be modified to ease the task of climbing stairs.	• Heavy load carried by the robot would deform its structure. • High humidity of environment could damage the circuit board of the robot.

The fabricated robot is stable due to its low centre of gravity and it could be controlled wirelessly. However, it cannot climb over the stairs with height more than 3 cm due to its limitation of body structure design. Besides that, large deviation error was found without compensated system. The implementation of the P-controller was used to compensate the error.

There are opportunities for this project to use the PID-controller for better performance to compensate the error more effectively compared to P-controller. However, this robot could not carried heavy load because it will deform the structure of the robot. High humidity of environment could also damage the circuit board of the robot as well.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

The study was undertaken with the aim to design and develop a crawler type robot which can pass through several types of terrains as well as to analyze and evaluate the performance of fabricated crawler type robot in term of its accuracy and repeatability. The findings of this project were based on the data collected during the experiments. It shows the deviation error is inversely proportional to the speed of the robot. In other words, deviation errors will be increased when the speed level of robot's motors is decreasing. Besides that, by implementing P-controller inside the system, the error managed to decrease compared to the uncompensated system. However, the compensated system only works effectively on regular terrain, but not in grass terrain. The suitable Kp gain for this controller was 0.8. Moreover, the robot could only climb over the dummy stairs lower or equal to 3 cm height. It could not climb over if beyond this value of height due to its limitation of robot structure design. However, the study was limited only to the flat surface and rough surface. For recommendation, it should cover the study of suspension system on more irregular terrains with extreme conditions such as stone, sand and mud. Besides that, it should include other types of controllers such as PI-controller, PD-controller and PID-controller to compensate the errors more effectively.

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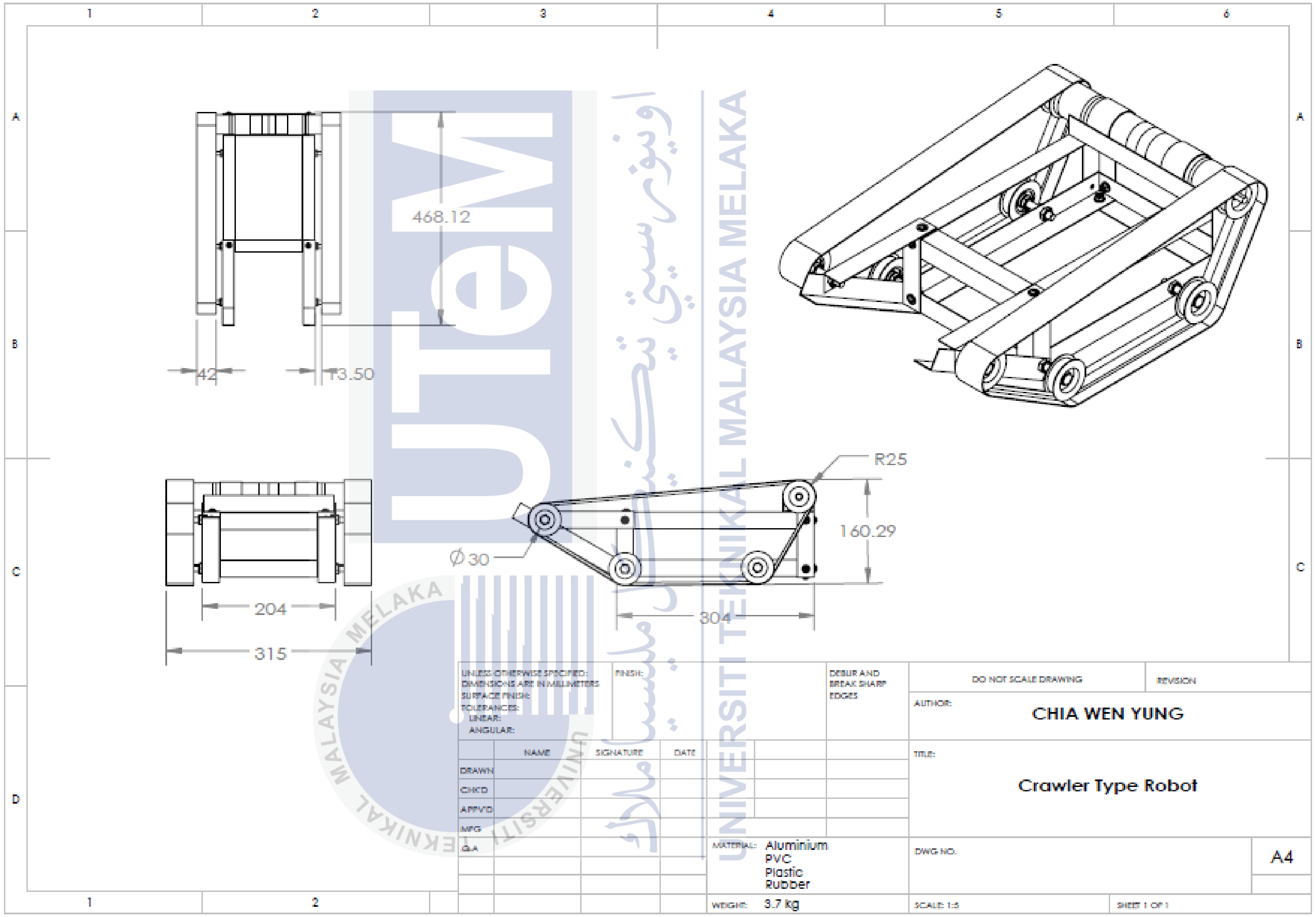
APPENDIX A

Detail drawing of proposed crawler type robot



APPENDIX B

Algorithm of uncompensated system

```
int skps(int data)
{
usart_write(data);delay_ms(5);
return usart_read();delay_ms(5);
}

void initmain()
{
 trisb=0b00001111;
 trisc=0b10000000;
 trisd=0b00000000;
 pwm1_init(5000);pwm2_init(5000);
 pwm1_start();pwm2_start();
lcd8_config(&portb,&portd,4,5,6,7,6,5,4,3,2,1,0);
 lcd8_cmd(lcd_clear);
 lcd8_cmd(lcd_cursor_off);
 lcd8_out(1,3,"CRAWLER TYPE");
 lcd8_out(2,8,"ROBOT");
 usart_init(9600);
}

void main()
{
 initmain();

 while(1)
 {
  if(skps(4)==0)
  {
   portc.f4=1;portc.f5=0;
   lcd8_out(1,1,"UP");

pwm1_change_duty(255);pwm2_change_duty(255);
  }

  else if(skps(6)==0)
  {
   portc.f4=0;portc.f5=1;
   lcd8_out(1,1,"DOWN");

pwm1_change_duty(255);pwm2_change_duty(255);
  }

  else
  {
   lcd8_cmd(lcd_clear);

pwm1_change_duty(0);pwm2_change_duty(0);
  }
 }
}
```

APPENDIX C

Algorithm of P-controller system

```
int cnta=0;
int cntb=0;
int a=0;
int b=0;
int n=0;
int m=0;
int Kp=0.8;
int PWM1=255;
int new=0;

int skps(int data)
{
usart_write(data);delay_ms(5);
return usart_read();delay_ms(5);
}

void initmain()
{
 trisb=0b00001111;
 trisc=0b10000000;
 trisd=0b00000000;
 pwm1_init(5000);pwm2_init(5000);
 pwm1_start();pwm2_start();

lcd8_config(&portb,&portd,4,5,6,7,6,5,4,3,2,1,0);
 lcd8_cmd(lcd_clear);
 lcd8_cmd(lcd_cursor_off);
 lcd8_out(1,3,"CRAWLER TYPE");
 lcd8_out(2,8,"ROBOT");
 usart_init(9600);
}

void main()
{
 initmain();

 while(1)
 {
  n=portb.f2;m=portb.f3
  if((a==0)&&(n==1))
  {
   if(portb.f3==0)
   {cnta--;}
   else {cnta++;}
  }

  else if((b==0)&&(m==1))
  {
   if(portb.f2==0)
   {cntb--;}
   else {cntb++;}
  }

  else if(skps(4)==0)
  {
   portc.f4=1;portc.f5=0;
   lcd8_out(1,1,"UP");

pwm1_change_duty(PWM1+new);pwm2_change_duty(255);
  }

  else if(skps(6)==0)
  {
   portc.f4=0;portc.f5=1;
   lcd8_out(1,1,"DOWN");

pwm1_change_duty(PWM1+new);pwm2_change_duty(255);
  }

  else
  {
   lcd8_cmd(lcd_clear);

pwm1_change_duty(0);pwm2_change_duty(0);
  }

  a=n;b=m;
  new=Kp(cnta-cntb);
 }
}
```