ROBOT AUTOMATIK BERGERAK
YANG BERFUNGSI
PEGANG DAN LETAK

(PICK-AND-PLACE MOBILE AUTONOMOUS ROBOTS)

Oleh
CHAN JAAN HUAN
67494

Penyelia
DR. ZAHURIN SAMAD

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ABSTRAK

Tesis ini disediakan untuk menerangkan tentang pengetahuan dalam pembangunan robot automasi. Pengetahuan ini melibatkan pelbagai jenis langkah serta kriteria. Projek ini adalah mengenai tentang rekabentuk dan pembinaan sebuah robot automasi yang berfungsi untuk menjejaki mengikut garisan, mengesan radius bakul, memasukkan bola dan sebagainya. Robot ini direkabentukkan (bersaiz 500mm x 500mm x 1500mm sebelum pertandingan bermula dan dihadkan ketingginan sebanyak 2000mm setelah pertandingan bermula) untuk menyempurnakan tugas iaitu menjejaki melalui ladang pertandingan, sampai ke Oboh Utama, memutarkan Oboh Utama dan akhirnya memasukkan bola ke dalamnya. Dengan mengaplikasikan Pengagihan Fungsi Kualiti, robot tersebut telah berjaya direkabentukkan daripada beberapa alternatif yang dicadangkan. Robot ini telah direkabentukkan supaya ianya boleh dipisahkan kepada dua bahagian yang dinamakan sebagain Penghantar-EX dan Penyuap-EX. Bergantung kepada tugas masing-masing, sistem pengawalan telah dibina untuk menambahkan keberkesanan mereka. Akan tetapi, beberapa ujian seperti ujian penjejakan, ujian kelurusan, ujian penstabilan, ujian penahanan, ujian pemanjangan, ujian pengesanan radius serta ujian pemasukan bola telah dijalankan supaya memastikan kebolehpercayaan mereka. Secara keseluruhannya, robot-robot ini telah mencapai prestasi yang memuaskan. Manakala, adalah dicadangkan bahawa tali elastik yang digunakan untuk menggantikan mekanisme yang kompleks perlu ditukarkan setelah tiga kali penggunaannya untuk memastikan ianya berfungsi dengan sempurna.

ABSTRACT

This thesis presents a Research and Development study on building Pick-and-Place Mobile Autonomous Robot (MARS). It considers various steps and criteria during the study. This project is mainly regarding on designing and fabricating an autonomous robot which posses the functions such as line tracking, sense section radius of the Canister, feed in the Rubber Balls, etc. This robot is designed (in the size of 500mm x 500mm x 1500mm before the game start and limited 2000mm in height after the game start) to accomplish tasks which are tracks through the game field, reaches the Main Torch, rotates the Main Torch and finally feed the Rubber Balls into the Canister. By applying Quality Function Deployment (QFD), robot was successfully designed from the several alternatives. It was designed to be detachable to form two robots named as EX-Transporter and Feeder-EX. According to their tasks, control systems were built to enhance the efficiency of the robots. However, several tests were conducted to ensure their reliability, such as tracking test, straightness test, robot stabilizing system test, defending system test, robot extending system test, radius sensing system test and Rubber Balls feeding system test. As a result, these robots achieve a good performance through the tests. However, it is recommended that, elastic strings which were used to replace the complex mechanism needed to be changed after three times of usage to ensure its functionality.

CHAPTER 1
INTRODUCTION

1.1 ROBOCON

RoboCON is actually an international robotics competition began in 1988 which was established and based in Japan. It is organized by a television broadcaster, NHK. It is an oldest and most prestigious annual robotics event in the world. The objective of this competition is enable a mechanically oriented robotics challenge testing a range of engineering design skills, including the challenge is different, and frequently combines the best of both manual control and autonomous control of the robotics.

For ABU Pacific Robot Contest 2005 Beijing, the theme is set as “Climb on the Great Wall, Light the holy fire”. The Great Wall is one of the greatest feats of construction the world has ever seen. This ancient monument is not only a cultural heritage site with great significance for China, but also a major tourist attraction, known all around the world. Foreign tourists know that a visit to China is not complete without a trip to the Great Wall, a symbol of China’s ancient civilization and humankind’s powerful ability to shape our surroundings. There is an old Chinese saying: “You are not truly a strong man until you have climbed to the top of the Great Wall”.

The aim of this contest is to climb the Great Wall and feed Fuel Balls into five Torches and four Bonfires by collaboration between Manual and Automatic machines. The duration of each match is three minutes.

1.2 PROBLEM STATEMENT

The Main Torch which is 1800mm in height is set in the center of the game field. It is divided into red, blue and green portions, called the red, blue and green Fuel Canisters, equally by colored clapboards. Thus, it can rotate around the axis of its own pole in each game, if external force is applied as shown in Figure 1.2. In order to accomplish the task, at least one Fuel Ball, which is miniature rubber basketball 150mm in diameter and 150g in weight needed to be fed into both of its own and green canisters in the Main Torch.

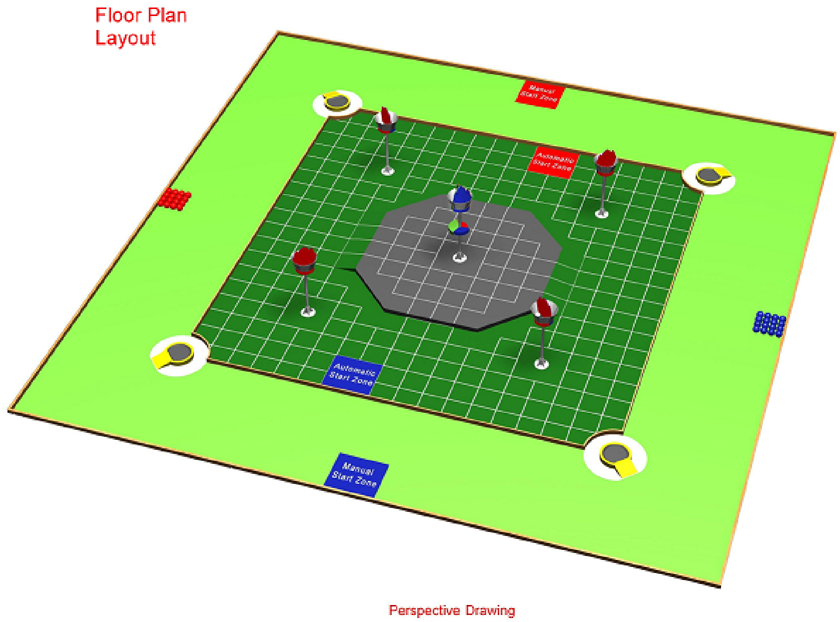

Figure 1.1: Game Field of RoboCON 2005

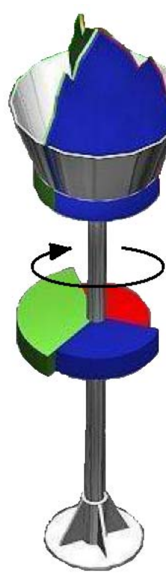

Figure 1.2: Main Torch which can be Freely Rotated

In order to complete the above tasks, the robot needed to be designed in the form of knowing image recognizing, picking and placing the object (Fuel Ball) since these are the basic function of an ordinary robot. Besides, additional functions are also needed so that the robot can perform an outstanding task.

1.3 OBJECTIVE

1. To make a mobile robot by hand from design to construction to compete the task, which is to feed the Fuel Ball, which is miniature rubber basketball into both of own, and green canister in the Main Torch.
2. To enable line tracking function becomes part of the robot.
3. To develop a robot that could sense section radius of the Fuel Canisters
4. Able to feed rubber balls according to the color of the Fuel Canisters.

1.4 SCOPE OF THE PROJECT

According to the rules ABU Asia • Pacific Robot Contest 2005 Beijing, the mobile autonomous robot of this project should work with in the Automatic Zone which is 9000mm × 9000mm in a square form. Besides, the robot should able to climb up on an octagon upland area, which is known as Beacon Tower Zone, of 100mm in height, located in the center of the Automatic Zone. The designed robot should come to this area and feed the Fuel Balls in to both of owned and green canister of the Main Torch. During feeding the Fuel Ball, the robot should able to rotate the Main Torch in order to feed the right ball in to the right canister. Other than that, the rules also state that the robot of this project must be started by one operation and it is allowed to go into any zones except the Bonfire Zones and space over it. It is also not allowed to communicate with each other autonomous machines in any other way. The robot should be design to perform tasks by using voltage of the machines' electrical power supply not more than 24VDC. Thus, the complete set of robot should not exceed 10kg.

To ensure the 4 autonomous robots to cooperate with each others, it is needed to be designed to fit in an area of 500mm × 500mm square form and it is also cannot exceed the height limit which is 1500mm before the start of the game and 2000mm after the start of the game. After the game is start, the robot should able to feed the Fuel Ball which 150mm in diameter and 150g in weight into the correct canister. Finally, the design of the robot must not attempt to cause damage to the game field, its equipments, including Fuel Balls arrangement in the opponent's Fuel Stock or the opponent machines.

1.5 APPROACH OF THE PROJECT

This is a project to discover and develop some fundamental scientific principles and practices that are applicable to intelligent mobile robot. It needs the integration between each component of the robot so that it can perform well to work as an ordinary "Pick and Place Mobile Autonomous Robot (MARS)".

From the idea generation to the structure fabrication, it involves several stages. During the task had been assigned, ideas needed to be generated to accomplish the problem statements, which are specified in the task. A rough design is hand drafted and according to this, it is then drafted by using AutoCAD. During this stage, several idea models can be visualize so that to prioritizing the best alternative.

When the best alternative is chosen, it is then to draw the detail engineering drawing of each component and part of the robot by using SolidWorks 2003 to finalize that the chosen alternative is feasible. At this moment, the developed application such as degree of freedom and workspace of each joint can be determined visually according to the simulation by using SolidWorks 2003.

When the chosen alternative is proved feasible, it is then to fabricate the model of the mobile robot. This is an important stage in which each part of the mobile robot needed to be fabricated according to the discussed alternative so that it can perform as intended. Besides, this stage also involves different kinds of manufacturing process such as machining, drilling, etc. At the same time, all the electrical and electronic parts also needed to be installed during the assembling of the structures.

To ensure to project is accomplished systematically and punctually, a plan or schedule has been developed. According to the scope of the project, the needed activities are listed down and planned. Its purpose is to make sure all of the detail activities are shown and no single step is neglected. The activities which needed to accomplish the project is shown in Table 1.1. (Shtub A., Bard J. F. and Globerson S., 1994)

Table 1.1: Activities and Duration of the Project

Activities	**Symbol**	**Duration (day)**
Development of design	A	7
Drafting by using AutoCAD	B	4
Prepare detailed engineering drawing by using SolidWork 2003	C	8
Design review	D	7
Fabrication according to design	E	26
Assembling including mechanical, electrical and electronic parts	F	34
Programming or the robot	G	10
Testing of the mobile robot	H	24
Quality assurance review	I	10
Thesis preparation	J	120

From the above activities, a Critical Path Method (CPM) shown in Figure 1.2 has been used to determine to total time to accomplish whole project and also time for each single activity. Besides, Gantt chart (Chart 1.1) is also used to arrange the activities to be accomplished accordingly. From the CPM and Gantt chart, it shows that the project will be accomplished in 120 days.

From the developed plan, the project is estimated to be start on 1st of November 2004 and complete on 28th of February 2005. The starting date of each activity is stated in the Gantt chart.

1.6 ORGANIZATION OF THE REPORT

Chapter 1 which is an introduction including the definition, background about the Pick and Place Mobile Autonomous Robot and ROBOCON, problem statement, objective, scope of the project and also the approach of the project.

However, in Chapter 2, it presents the literature review of the Pick and Place Mobile Autonomous Robots. It states out the knowledge about robotic including the basic structure and also the component.

Methodology of the design process will be discussed in Chapter 3. This chapter will describe about the process of designing the mobile autonomous pick-and-place robot. Besides, this chapter also states the design of the robot in detail. This includes the every single joint, link or motion involved in the designed robot. Other than that, explanations about the control system of the developed robot are discussed in detail during this chapter. The control system includes the sensory feedback system, etc.

In Chapter 4, tests for the robot are explained together with the results for each test.

According to the result, a review of the design is done in Chapter 5. During this chapter, every result of the tests is discussed in detail.

Finally, conclusion and suggestions on improving the design are made and stated in Chapter 6.

The detailed engineering drawings of all the parts of the robot, as well as the assembly drawing of the robot are appended in the Appendix.

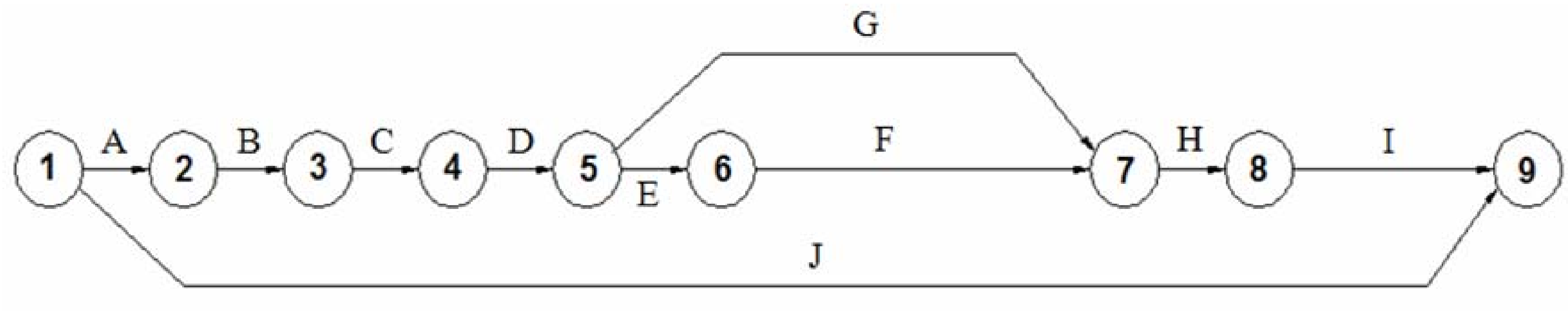

Figure 1.3: Network for the Project Using CPM

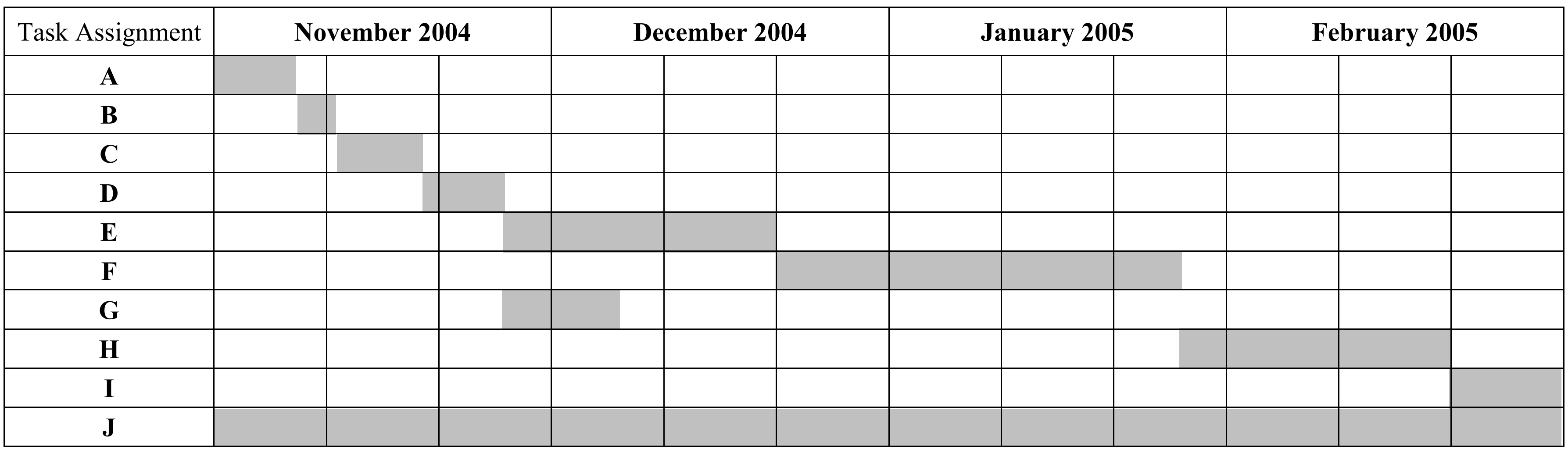

Chart 1.1: Gantt Chart and the Project Activities

CHAPTER 2
LITERATURE REVIEW

2.1 DEFINITION OF A 'ROBOT'

"A reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through various programmed motions for the performance of a variety of tasks"

(Robot Institute of America, 1979)

2.2 BACKGROUND OF THE 'ROBOT' AND 'ROBOTIC'

The Czech playwright Karel Capek from Czech word for forced labor or serf first coined the word 'Robot'. The use of word "Robot" was introduced into his play R.U.R. (Rossum's Universal Robots) which opened in Prague in January 1921.

The term 'robotics' refers to the study and use of robots. The term was coined and first used by the Russian-born American scientist and writer Isaac Asimov. It was first used in Runaround, a short story published in 1942. *I, Robot*, a collection of several of these stories, was published in 1950. Asimov also proposed his three "Laws of Robotics", and he later added a 'zeroth law'.

- **Law Zero**
  A robot may not injure humanity, or, through inaction, allow humanity to come to harm.
- **Law One**
  A robot may not injure a human being, or, through inaction, allow a human being to come to harm, unless this would violate a higher order law.
- **Law Two**
  A robot must obey orders given it by human beings, except where such orders would conflict with a higher order law.

- **Law Three**

  A robot must protect its own existence as long as such protection does not conflict with a higher order law.

The first industrial modern robots were the Unimates developed by George Devol and Joe Engelberger in the late 50's and early 60's. Robots have seven main components and each of the components is integrated together to perform an assigned task or job. The 7 main components are:

- **Body**

  This is the main body of the robot, which consists of different kind mechanical structure such as upper frame and base. (Wise E., 2003)

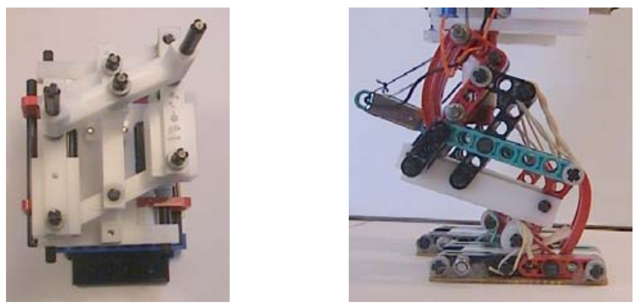

Figure 2.1: Mechanical Structures of Mobile Robot

- **End effectors**

  This is the part of the last joint which similar to the human hand of a manipulator. It can perform objects handling, other machines connections or any other assigned tasks.

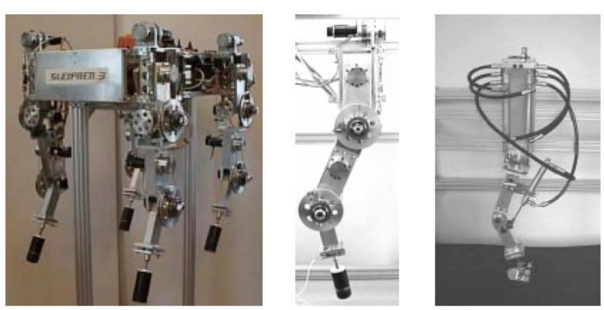

Figure 2.2: End Effectors

- **Actuators**

  This component is similar to the muscle of the manipulators to enable the joints, links or other mechanical structure capable to move at the determined speed and distance.

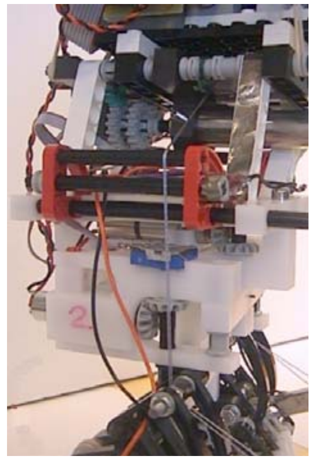

Figure 2.3: Actuators System of Mobile Robots

- **Sensors**

  Sensors are electronic devices to collect information about the internal state of the robot or to communicate with outside environment. This is device will give the feedback to the processor in order to command the robot so that all of its links, joints or other mechanical structure move as intend.

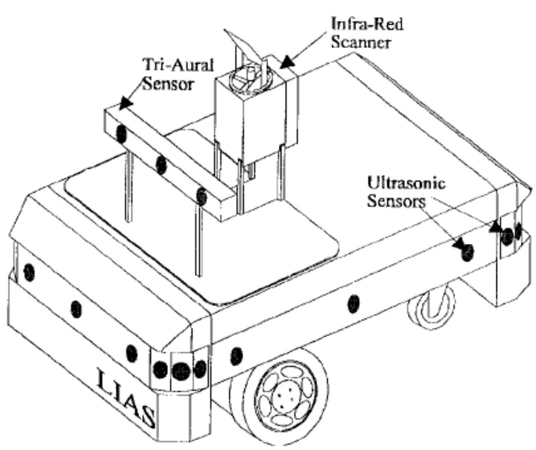

Figure 2.4: Sensors of the Mobile Robots

- **Controller**

  This part is similar to the human cerebellum and it is use to receive its data from the computer, controls the motions of the actuators and coordinates the motions with the sensory feedback information.

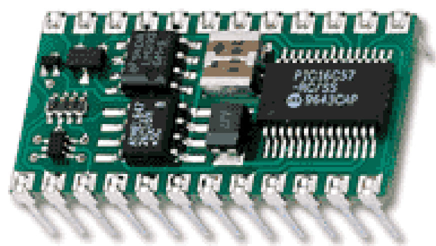

Figure 2.5: Controller

- **Processor**

  This is the most important part of the robot because it is similar to the function of the brain for human. It can calculates the motions of the robot's joints, determines how much and how fast each joint must move and oversees the coordinated action

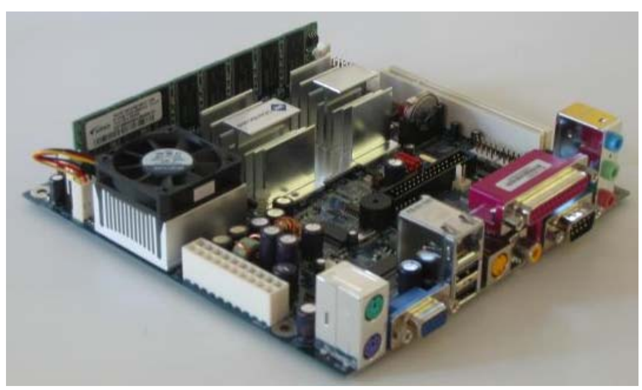

Figure 2.6: Processor and the Main Board

- **Software**

  Generally, there are three groups of software, which are operating system to operate the computer, robotic software to calculate the necessary motions of each joint and collection of routines and application program to use the peripheral devices of the robots.

2.3 ROBOT JOINTS

Generally, joints of robot can be divided into linear, rotary, sliding, or spherical. In fact, spherical joint are common in many robotic because they have high degree of freedom. However, it is also difficult to control. Therefore, robot with spherical joints is not common in the industrial field, except in research.

Most industrial robots have either a linear (prismatic) joint or a rotary (revolute) joint. Prismatic joint is a joint that move in linear direction and no rotation is allow. However, revolute joint is a joint that move in rotary motion and there is no linear motion with it.

2.4 ROBOT CHARACTERISTIC

To determine whether the robot is suitable according to the assigned task, there will be several robot characteristics or specifications needed to know.

- **Reach**
  This characteristic shows that the maximum distance a robot can reach with its joints or end effectors. It is also can be known as its work envelope.
- **Payload**
  It is the weight, which the robot can afford to carry without affecting its performance. It means that its maximum load capacity may actually larger than its specified payload.
- **Precision**
  This defines as how accurately a specified point can be reach by the end effectors of the robot as intended.
- **Repeatability (variability)**
  This characteristic determines how accurately the same specified point can be reach by the end effectors of the robot after repeated for many times. In fact, a robot may not reach the same point every time, but the end effectors may touch a certain radius from the desired point. The radius of a circle that formed is known as the repeatability.

2.5 ADVANTAGES OF THE ROBOT

- **Reduce labor cost**

  It can replace human workers, or enabling fewer workers to run semi-automatic equipment. Thus, it also can reduce training costs because when it is programmed, it can run on itself with the least intervention of human worker.

- **Reduce quality costs**

  Robot can perform automated inspection. As a result, it can reduce variation in product outputs.

- **Increase product variety**

  A flexible robot can perform variety of tasks by only changing the program of it.

- **Improve efficiency**

  Robots such as automated materials handling (AMH) and automated guided vehicles (AGV) can improve efficiency of transportation, storage and retrieval of materials. This can also reduce inventory in process.

- **Reduce lead time**

  Robot can perform a short assembling process and so manufacturing time.

- **Reduce accidents in the working environment**

  By having a good preventive maintenance, robots can minimize the percentage of accidents in the working environment.

- **Improve the quality of human life**

  Robot can replace human workers to perform task in an undesired, dirty and dangerous working conditions.

CHAPTER 3
METHODOLOGY

3.1 QUALITY FUNCTION DEPLOYMENT (QFD)

Quality Function Deployment is an important procedure in design and redesign process. This method enable the designer well understood the problems. Besides, it is also useful in determining and understanding the requirement of the design.

Quality Function Deployment is presented in the form of table. The table consists of design requirements, design criterions, engineering requirement and the project target. In order to get a design that meet the objective and target of the project, QFD is the first step that need to be done in beginning of the design project.

There are six steps needed to be followed in translating the design requirements to firm engineering targets. The six steps are identifying the user, determining design requirements, determining relative importance of the requirements, competition benchmarking, translating design requirements into measurable engineering requirements and setting engineering targets for the design.

3.1.1 Six Steps of QFD

Step 1: Identifying the User

This is the first step needed to be determined. It is important because the project may have different kind of usage when it is applied in different field. The user of this project is the participant of RoboCON 2005.

Step 2: Determining Design Requirements

Design requirements are according to the rules of RoboCON 2005. In addition, additional requirements are given by advisors (lecturers) to ensure the ability of the robot is able to defeat extra challenges.

Step 3: Determining Relative Importance of the Requirements

This step emphasizes evaluation the important of each of the design requirements. Each of the requirements is weighted according to relative importance. To determine importance, a pair wise comparison technique is used to compare each of the requirements. This method lends a lot of insight into which requirements should receive the most attention.

Step 4: Competition Benchmarking

A comparison is made between the designs. In order to determine how the user perceives the competition's ability to meet each of the requirements, the designs are being compared. As a result, the best design will be chosen for fabrication.

Step 5: Translating Design Requirements into Measurable Engineering Requirements

There is a need to transform design requirements to engineering requirements and a need to make sure that each engineering requirement is measurable. It is important in order to develop a set of engineering requirements or often called as a design specifications that are measured for use in evaluating proposed design. Each design requirements that are related with the engineering requirements are weighted according to the relative important.

Step 6: Setting Engineering Targets for the Design

A set of target value for each engineering measure is determined. Then these target values are used to evaluate the design's ability to satisfy design requirements. Also, the values that are obtained by measuring the competition give a basic for establishing the targets in the process of design.

3.2 CONCEPTUAL DESIGN

3.2.1 TRACKING PATH

Design Requirements

- Fast to reach Main Torch
- Light weight

Relative Importance of the Requirements

Table 3.1: Relative Importance of the Requirements in Tracking Path of the Robot

Requirements		Total	%
Fast to reach Main Torch	1	1	100
Light Weight	0	0	0

Note: Pair comparison is done relatively on each requirement. For example, the requirement of fast to reach Main Torch is compared with light weight, 1 score is given for the more important requirement and less important is given 0 score

Benchmarking

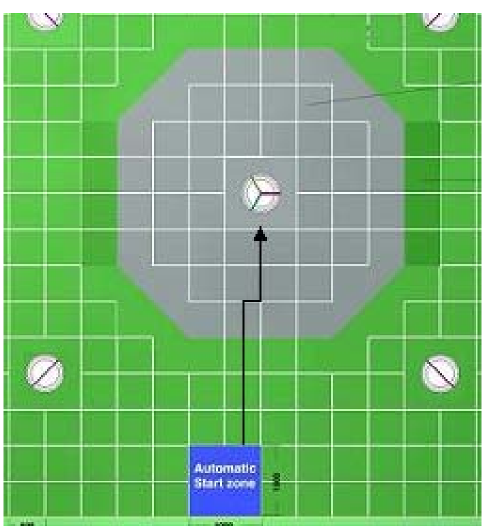

Figure 3.1a: First Alternative of Tracking Path for the Robot

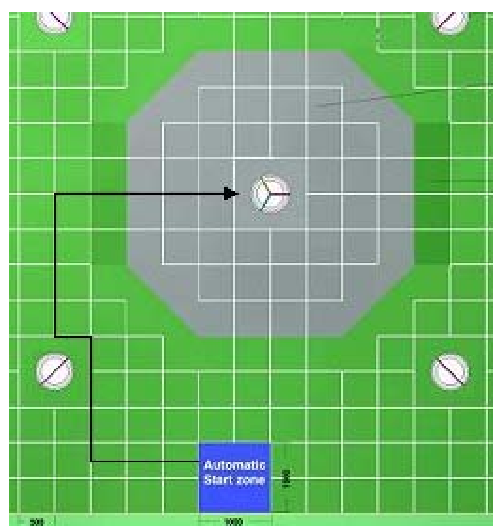

Figure 3.1b: Second Alternative of Tracking Path for the Robot

Since Fast to reach Main Torch was more important than light weight, therefore, distance of the path is chosen as the standard of doing benchmarking. For the first alternative, robot needs to track 3.5m to reach Main Torch. However, for the second alternative, robot needs to track 8.5m to reach Main Torch.

3.2.2 TRACKING SYSTEM

Design Requirement

- Easy to climb on the stage
- Fast to climb on the stage

Relative Importance of the Requirements

Table 3.2: Relative Importance of the Requirements in Tracking System of the Robot

Requirements		Total	%
Easy to Climb on the Stage	0	0	0
Fast to Climb on the Stage	1	1	100

Benchmarking

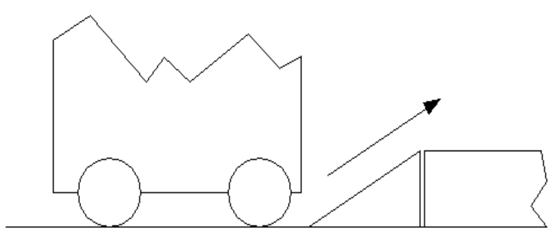

Figure 3.2a: First Alternative of Tracking System for Robot

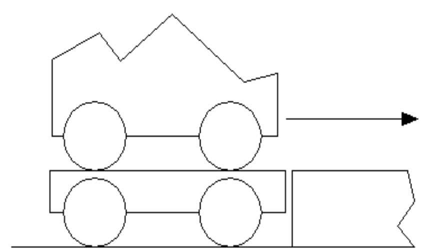

Figure 3.2b: Second Alternative of Tracking System for Robot

For the first alternative, the robot which is estimated 15kg needs to track along the. Assume that the slope which was used is 1:5, as a result, two free body diagrams can be built as shown in Figure 3.3 and Figure 3.4.

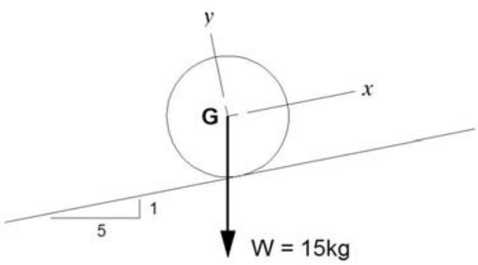

Figure 3.3: Wheel Tracking on the Slope

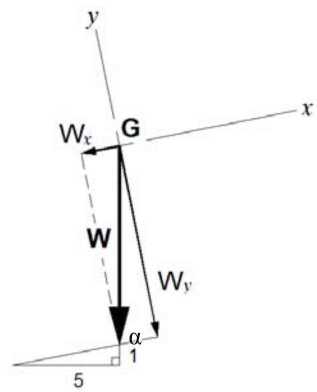

Figure 3.4: Free Body Diagram of the Wheel in First Alternative

From the above figures, the 15kg weight can be resolved into components along the horizontal axis as follow,

$$\cos \alpha = \frac{1}{\sqrt{26}} \qquad \sin \alpha = \frac{5}{\sqrt{26}}$$

Therefore,

$$W_x = -(15\text{kg}) \frac{1}{\sqrt{26}}$$

$$= -2.9417\text{kg}$$

$$W_y = -(15\text{kg}) \frac{5}{\sqrt{26}}$$

$$= -14.7087\text{kg}$$

However, for the second alternative, the robot tracks along the horizontal axis as shown as below,

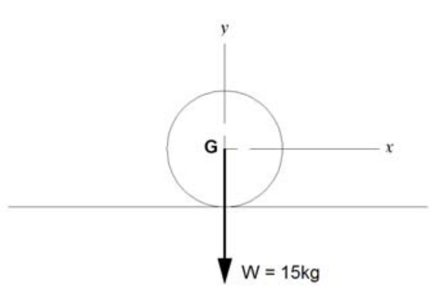

Figure 3.5: Free Body Diagram of the Wheel in Second Alternative

From Figure 3.5, the 15kg weight can be resolved into components along the horizontal axis as follow,

W_x = 0kg W_y = - 15kg

(Cheng, 1998)

In this case, we focus on W_x, which is the force that needs motors to overcome. For the second alternative, motor is only need to drive the robot forward or backward without considering any negative forces (W_x = 0kg). However, for the first alternative, motor is needed to overcome the negative force (W_x = -2.9417kg) when it needs to drive the robot forward. In another word, it could save more power in the second alternative for other usage.

As a result, second alternative is chosen.

3.2.3 ROBOT EX-TRANSPORTER

Since the second alternative shown in section 3.2.2 was chosen, therefore, two robots needed to be built. The smaller robot named as EX-Transporter works as a transporter, however, the bigger robot which named as Feeder-EX works as Rubber Ball feeder.

Design Requirement

- Easy to transport Feeder-EX to the stage
- Light weight
- Reasonable size
- Easy to operate

Relative Importance of the Requirements

Table 3.3: Relative Importance of the Requirements in Designing Robot EX-Transporter

Requirements						Total	%
Easy to transport Feeder-EX	1	1	1			3	50
Light Weight	0	-	1	1		2	33
Reasonable Size		0	0	-	1	1	17
Easy to Operate			0	0	0	0	0

Benchmarking

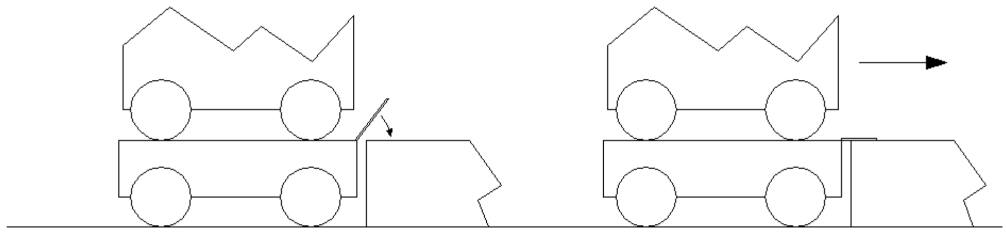

Figure 3.6a: First Alternative of Design for EX-Transporter

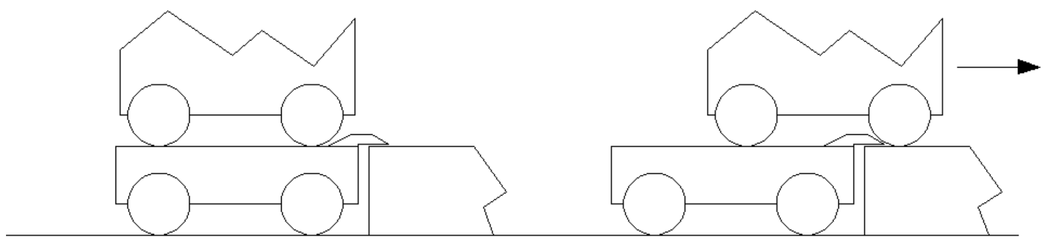

Figure 3.6b: Second Alternative of Design for EX-Transporter

For the first alternative as shown in Figure 3.6a, a mechanism needed to be designed to enable the bridge fall across the stage. In this case, sensor is needed to sense the existing of the stage in order the bridge will fall down at the suitable position.

However, for the second alternative as shown in Figure 3.6b, a fixed bridge is assembled at the front of the EX-Transporter. When EX-Transporter stops against the stage, Feeder-EX can track across the fixed bridge without any additional mechanism. Thus, it achieves the most emphasized requirement as mentioned before.

Since easy to operate is the main criteria to be considered, the first alternative needs one degree of freedom, but second alternative do not need any mechanism to achieve the criteria. Due to this, second alternative is chosen as the required design.

3.2.4 STABILIZING SYSTEM OF FEEDER-EX

When Feeder-EX which works as a Rubber Balls feeders, reaches to the Main Torch, it need to be stabilize before feeding a balls accurately.

Design Requirement

- Easy to operate
- Light weight
- Would not detach easily

Relative Importance of the Requirements

Table 3.4: Relative Importance of the Requirements in Stabilizing System of Feeder-EX

Requirements				Total	%
Easy to Operate	1	1		2	67
Light Weight	0	-	0	0	0
Won't Detach Easily		0	1	1	33

Benchmarking

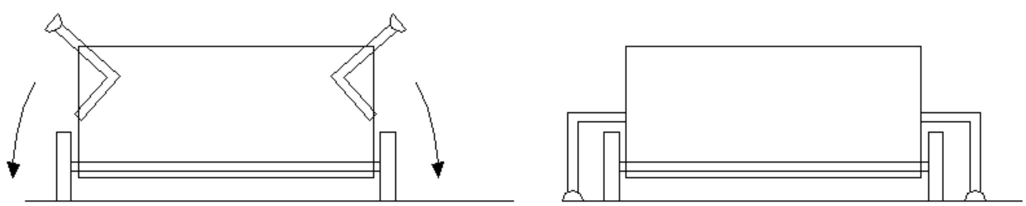

Figure 3.7a: First Alternative of Stabilizing System for Feeder-EX

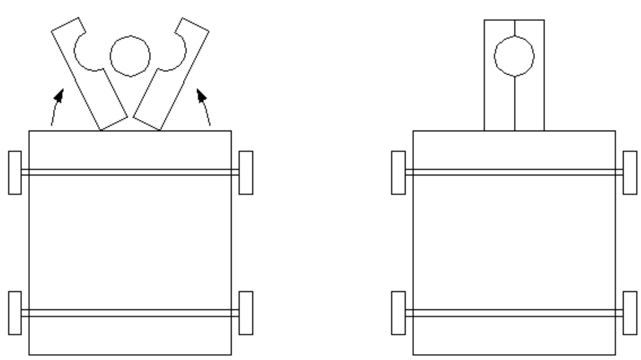

Figure 3.7b: Second Alternative of Stabilizing System for Feeder-EX

As shown in the Table 3.4, easy to operate has become the most important criteria to be considered. As shown in the designed alternatives, both of them have one degree of freedom. Therefore, second important criteria, which is would detached easily has draw the main concentration on analysis.

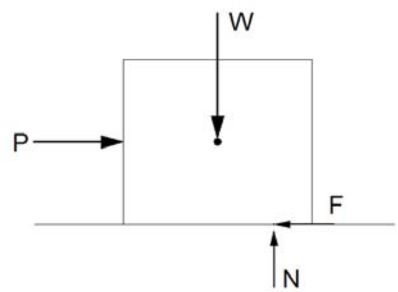

Figure 3.8: Free Body Diagram on Stabilizing System for Feeder-EX

By referring to the above figure, the effect of the distributed normal and frictional loadings is indicated by their resultants **N** and **F**. **F** is always acts tangent to the contacting surface, opposite to the direction of **P**. on the other hand, the normal force **N** is directed upward to balance the robot's weight **W**. When the frictional force **F** may not be great enough to balance **P**, and consequently the robot will tend to slip. (Hibbeler R. C., 1998)

For the first alternative, once it is slip, there will be no chance to feed the Rubber Balls into the Canister accurately. However, for the second alternative, it still may able to feed in the Rubber Balls although it was knocked. This is because of its clamping system which clamping the Main Torch. When the robot is knocked, it will only slip circularly around the Main Torch. Therefore, second alternative is chosen for the design.

3.2.5 EXTENDING SYSTEM OF FEEDER-EX

As mentioned in the rules and regulations, the height of the robot may not exceed 1500mm before the game start. However, the height of the Main Torch is more than 1800mm. In order to feed in the Rubber Balls, the robot must be able to extend its body to achieve the height of the Main Torch.

Design Requirements

- Easy to operate
- Light weight
- Reasonable size

Relative Importance of the Requirements

Table 3.5: Relative Importance of the Requirements in Extending System of Feeder-EX

Requirements				Total	%
Easy to Operate	0	0		0	0
Light Weight	1	-	1	2	67
Reasonable Size		1	0	1	33

Benchmarking

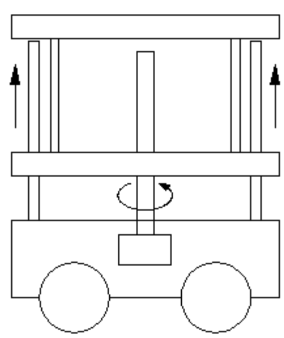

Figure 3.9a: First Alternative of Extending System for Feeder-EX

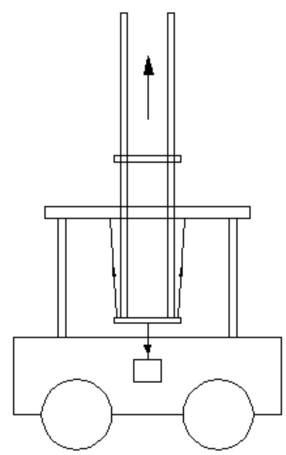

Figure 3.9b: Second Alternative of Extending System for Feeder-EX

By referring to Table 3.5, light weight is emphasized more than others. By comparing both of the alternatives, first alternative needs at least a steel bar with thread to control the body extending. The steel bar is assembled to the motor, when it is rotated, the body will begin to move up.

However, for the second alternative, only elastic strings are needed to pull up the body. It is controlled by using another string, which is tighten at the motor in order to monitor the body extending. Therefore, obviously the second alternative will be chosen as the design.

3.2.6 MAIN TORCH ROTATING SYSTEM OF FEEDER-EX

Main Torch is a torch that can be freely rotated when external force is applied. Its main purpose is to allow robots to rotate until the desired section of Canister has come.

Design Requirements

- Easy to operate
- Light weight
- Reasonable size

Relative Importance of the Requirements

Table 3.6: Relative Importance of the Requirements in Main Torch Rotating System of Feeder-EX

Requirements				Total	%
Easy to Operate	1	1		2	67
Light Weight	0	-	1	1	33
Reasonable Size		0	0	0	0

Benchmarking

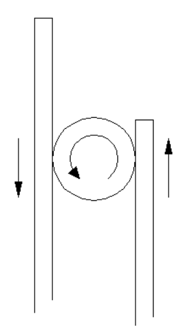

Figure 3.10a: First Alternative of Main Torch Rotating System for Feeder-EX

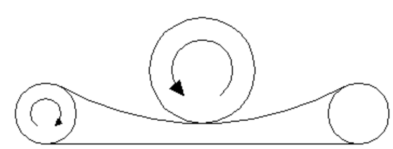

Figure 3.10b: Second Alternative of Main Torch Rotating System for Feeder-EX