Designing Omni-Directional Mobile Robot Platform for Research

by

Le Bang Duc

Dissertation submitted in partial fulfilment of
the requirements for the
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(Mechanical Engineering)

May 2008

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Programme
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Approved by,

____
(Associate Professor Dr. Fakhruldin Mohd Hashim)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2008

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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(LE BANG DUC)

ABSTRACT

Machines, as a key workforce in manufacturing, mining, construction, are essential for industry, and socially. However, existing mobile robots' designs do not provide enough mobility and maneuverability. This is one of the major factors that requires an improved design of mobile robot platform.

This thesis is focused on designing an improved Omni-directional robot platform that has good mobility and maneuverability. To realize these conditions, a lot of criteria and constraints need to be considered in the design process. The conceptual design flows of this mobile robot are to satisfy the need of a mobile robot platform, establish Omni-directional mobile robot specifications followed by concept generation and concept selection.

A full decomposition of Omni-directional mobile robot was done. This was followed by building a morphology chart to gather several ideas for those sub-functions of mobile robot. Combination of different types of sub-functions will generate several new Omni-directional mobile robot concepts. The concepts were drafted by using Three-dimensional (3-D) Computer Aided Designing SOLIDWORKS software. After concept generation, the concepts were evaluated by using weighted decision matrix method. The best concept was generated from 3-D design to get 2-D technical drawing and kinematics analysis. These analysis and results of the robot performance are presented in this thesis.

ACKNOWLEDGEMENTS

The authors of this dissertation would like to thank Dr. Fakhruldin Mohd Hashim and Mr. Mark Ovinis for their continuous guidance and support. The authors also like to express appreciation to the Mechanical Department, Electrical and Electronics Department of Universiti Teknologi PETRONAS, Microchip Inc. and National Semiconductor Inc., which had provided all the necessary technical supports, usage of equipments and products sponsors for the research project, without which this project can not be accomplished.

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CHAPTER 1

INTRODUCTION

1.1 Background

Machines, as a key workforce in manufacturing, mining, construction, are essential for industry, and socially. In the near future, robots will replace all machines and even human in certain tasks.

There are two main categories of robots have been developed around the world, one is industrial robot normally being referred to as manipulator, and another one is mobile robot. Recently, higher mobility and autonomy have been required in designing of robots for different applications. In view of this increasing demand, the conventional wheeled type robots have become the weakest point in all range of specifications. In addition to their poor turning radius, and energy consumption, conventional robots have problems to move in any direction [1].

With those solid reasons, a new design which able to provide high mobility and maneuverability is essential. The design should be able to serve a better quality and performance if compare with conventional design. In order to design a better performance of Omni-directional mobile robot, several important steps of design are needed to be followed so that the design could cope to basic requirement of mobile robot. According to product design and development process, there are few crucial steps such as identify need, product specification, morphology chart and others needed to be gone through in order to avoid any costly product when proceed to fabrication process.

1.2 Problem Statement

Reflecting upon the mobility perspectives of a mobile robot, inadequate locomotion flexibility is a major factor leading to unable to work effectively in a confined workspace. As a consequence, the users have to spend extra money to hire human workers or at least the conventional wheeled robot would take more time and energy to move in such place as shown in Figure 1.1.

Moreover, energy consumption of robot is a big issue when comes to duration of continuous working without recharge, life time of battery (for battery powered robots), costs, and environmental effects.

Figure 1.1: Limited space in factory (left) or warehouse (right) [2].

1.3 Objectives

In this project, the main objective is to improve the existing design of an Omni-directional wheeled mobile robot platform for research. The objective can be further divided as follows:

- To carry out a study of existing Omni-directional mobile robot performance.
- To improve design of existing Omni-directional mobile robot.
- To analyze kinematics behavior of the Omni-directional robot.

1.4 Scope

This project will cover design process of an Omni-directional mobile robot platform for research. The design process will be divided into three sub-systems including mechanical assemblies, electronics circuit and embedded program. In each sub-system, the detailed design consideration from sub-system requirements to design and fabrication. Each sub-system will be developed separately to reduce complexity of the overall project, but the requirement specification will ensure the compatibility of sub-systems when combined.

Due to the lack of time, this study is not aimed to provide all the necessary information in designing Omni-directional mobile robot to be the robot platform in industrial scale. Instead, this study is hoped to serve as the starting platform in unlocking the potential of using Omni-directional mobile robot in the industry. In the recommendation section that would follow later in this report, the further steps that could be taken to study the Omni-directional mobile robot in a greater detail would be presented.

1.5 Methodology

In this project, the design process has been done as shown in Figure 1.3 below. Firstly, Omni-directional mobile robot's information was gathered, it was followed by the product decomposition. The robot will be decomposed into separate parts according to their own functions. Combination of each means of sub-function of mobile robot has generated few new mobile robot concepts. Each of the new concepts will be evaluated by using weighted matrix concept. The best concept is then moving towards fabrication of prototype. The best concept will also be taken for analysis such as 2-dimensional drawing and kinematics analysis. Details of each step are presented in chapter 3.

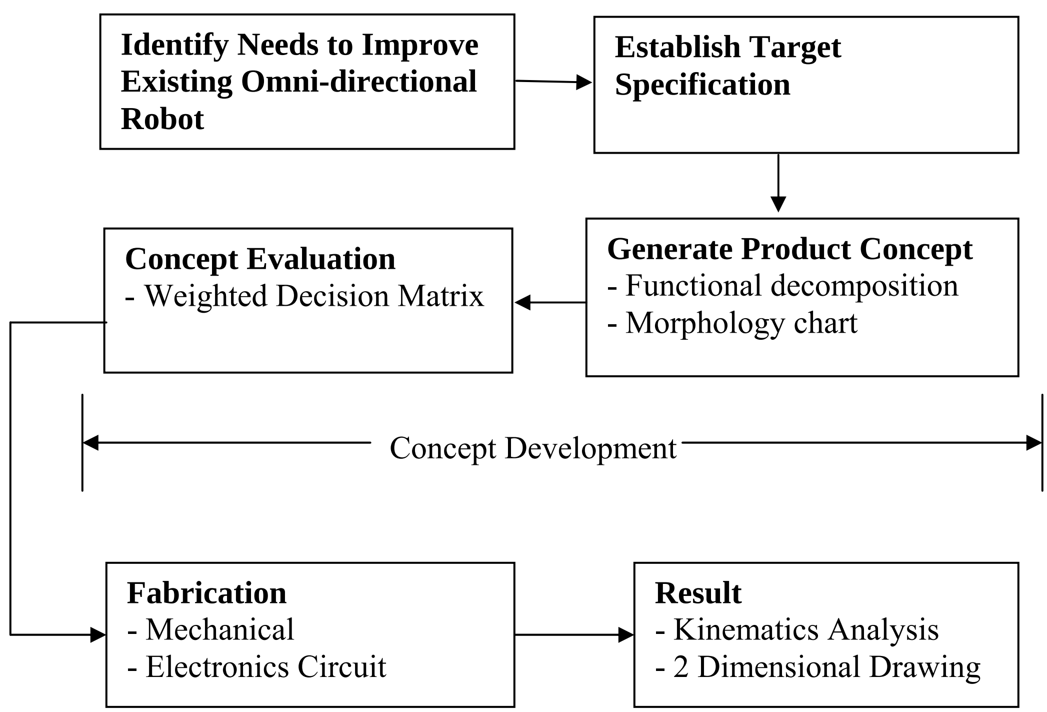


Figure 1.2: Product Design Process.

CHAPTER 2

LITERATURE REVIEW

2.1 Types of Mobile Robots

Mobile robots are robots which can move around to perform desired tasks in different environments with or without human guidance. Figure 2.1 shows different types of mobile robots being developed at Mobile Robot Lab (MRL), Georgia Institute of Technology, United States. Different robots can be autonomous in different ways. A high degree of autonomy is particularly desirable in fields such as space exploration or search and rescue, where communication delays and interruptions are unavoidable. For industrial use, the mobile robots normally go through predetermined path with simple close loop feed back. Autonomous Mobile Robot consists of basic components such as controller, sensors & transducer, analyzer, actuator, and drives. Recently, several mobile robots are developed all around the world, in many different forms, from bio-inspired robots such as snake robots to legged robots to wheeled type robots. Each and every mobile robot is unique in design and approach, but in general all of them have the similar goal – to locomote in different terrain, perform the tasks they are designed for [2].

Figure 2.1: Many types of mobile robots at MRL, Georgia Tech [4].

2.2 Omni-directional Robot and Omni Wheel

The conventional locomotion method using Akerman steering has some weaknesses that need to be improved, such as relatively large cornering radius and can not move sideway [5]. A robot that uses Omni-wheels can move in any direction, at any angle, without rotating beforehand. It can rotate about itself. It also can spin while translating forward at the same time.

2.2.1 Holonomic versus Non-Holonomic Robots

There are two types of mobile robots, holonomic robots and non-holonomic robots. Non-holonomic robots are ones that cannot instantaneously move in any direction, such as a car. This type of robot has to perform a set of motions to change heading. For example, if you want your car to move sideways, you must perform a complex 'parallel parking' motion. For the car to turn, you must rotate the wheels and drive forward. This type of robot would have '1.5' degrees of freedom, meaning that it can move in both the X and Y direction, but requires complex motions to achieve the X direction.

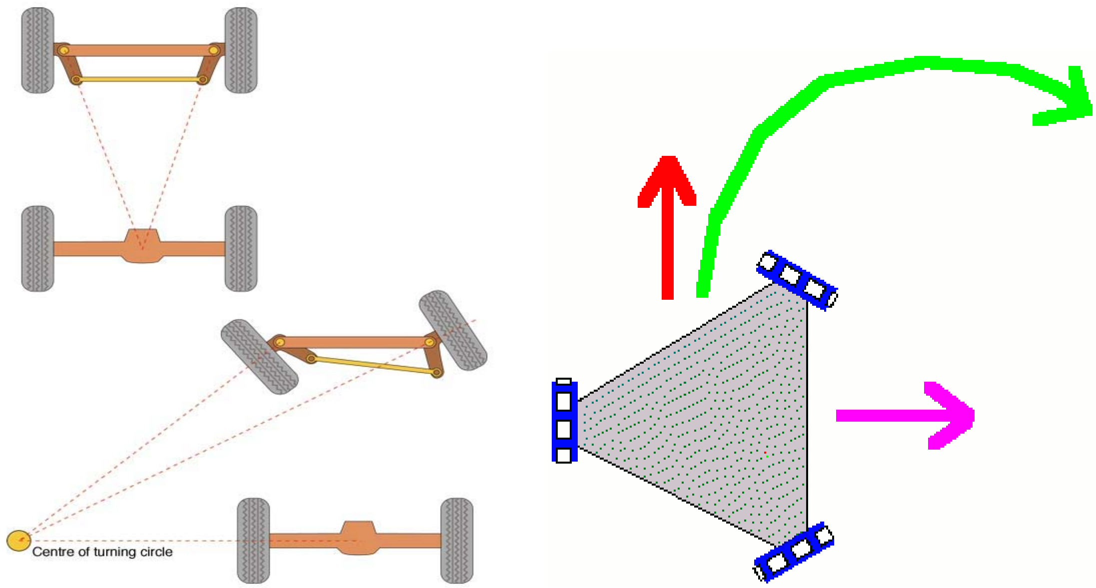


Figure 2.2 : Akerman steering (left) [5] and Omni-robot (right) [6]

A holonomic robot also known as Omni-robot however can instantaneously move in any direction as shown in Figure 2.2 above. It does not need to do any complex motions to achieve a particular heading. This type of robot would have 2 degrees of freedom in that it can move in both the X and Y plane freely.

2.2.2 Holonomic Configuration

There is variety of designs of Omni-directional or near Omni-directional vehicles have been developed. These can be broken into two approaches: special wheel designs and conventional wheel designs. An Omni-directional vehicle is usually formed using three or more of such wheels [7]. According to a conference proceeding by Yu [8], most special wheel designs are based on a concept that achieves traction in one direction and allow passive motion is another. The universal wheel is an example of the special wheel design that has a number of small passive rollers mounted on the periphery of a normal wheel. The wheel is driven in a normal fashion, while the rollers allow for a free motion in the perpendicular direction.

From the above reasons, Yu developed Omni directional robot using Active Split Offset Castors, he combined two normal offset castors (Figure 2.3) into one active split offset castor (Figure 2.4). Yu also developed kinematics analysis of the new castor, from that he found out by combination of two or more active split offset castors, as shown in Figure 2.5, center of the robot can achieve Omni-directional movements [8].

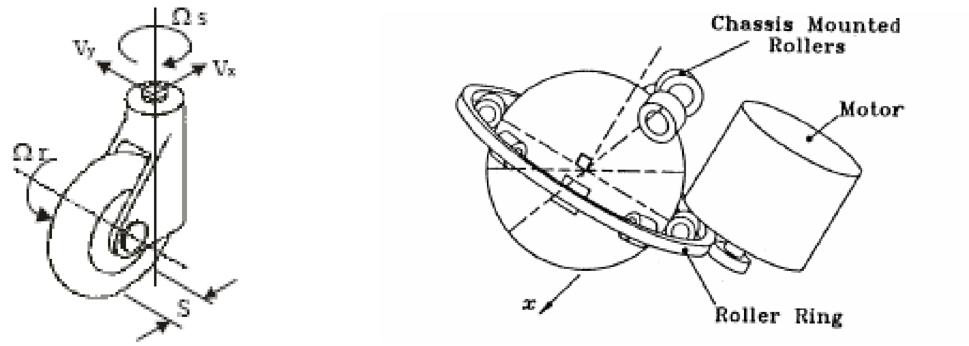


Figure 2.3: Normal offset castor (left) and ball castor (right) [8]

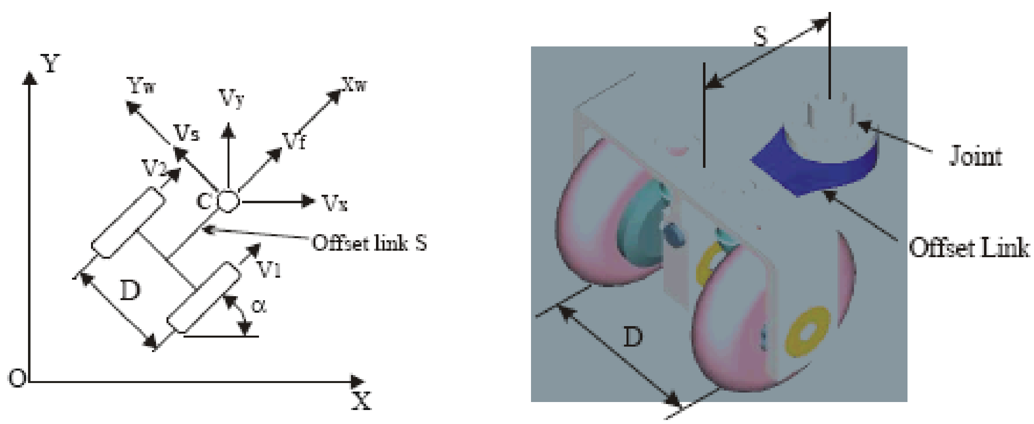


Figure 2.4: Proposed Active Split Offset Castors [8]

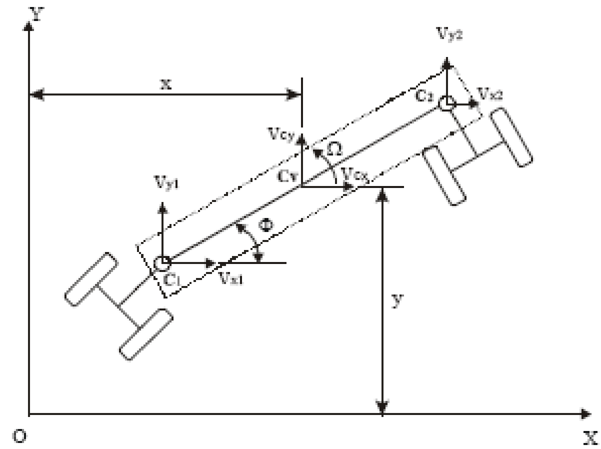


Figure 2.5: Combination of two Active Split Offset Castors can achieve Omni-directional movement. [8]

The mecanum wheel is one design for a wheel which can move in any direction. It is sometimes called the Ilon wheel after its Swedish inventor, Bengt Ilon, who came up with the idea in 1973 when he was an engineer with the Swedish company Mecanum AB [9]. It is a conventional wheel with a series of rollers attached to its circumference, these rollers having an axis of rotation at 45° to the plane of the wheel in a plane parallel to the axis of rotation of the wheel. As well as moving forward and backward like conventional wheels, they allow sideways movement by spinning a pair of wheels in opposite directions. The US Navy bought the patent from Ilon and put researchers to work on it in the 1980s in Panama City. The Navy has used it for transporting items around ships. In 1997 Airtrax Inc. and several other companies each paid the Navy $2,500 for rights to the technology, including old drawings of how the motors and controllers worked, to build an Omni-directional forklift truck that could maneuver in tight spaces such as the deck of an aircraft carrier. These vehicles are now in production and video footage can be seen on the Airtrax website [10].

There are several Omni-directional mobile robots using Mecanum wheels [11]. Figure 2.6 shows some of different types of Mecanum wheels and robots developed at Robotics Institute, Carnegie Mellon University (CMU) [3].

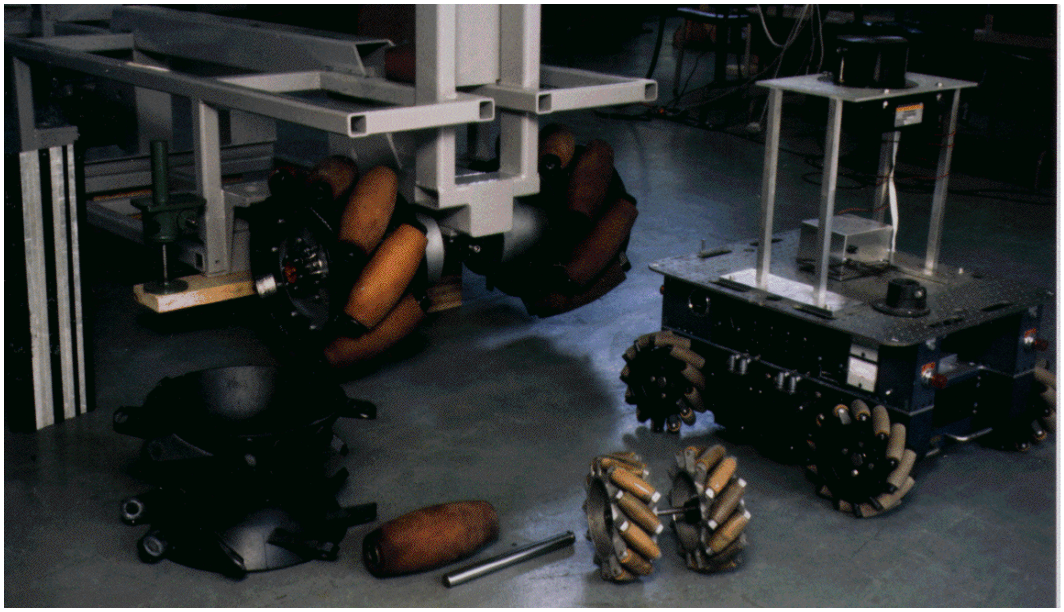


Figure 2.6: Robots using mecanum wheels at Robotic Institute, Carnegie Mellon University (CMU) [3].

Omni wheels shown in Figure 2.7, similar to mecanum wheels, are wheels with small discs around the circumference which are perpendicular to the rolling direction. The effect is that the wheel will roll with full force, but will also slide laterally with great ease. It is a method of creating holonomic drive. The combination of these two rolling elements provides a compact and inexpensive unit for moving heavy loads in any direction along a plane, doing so smoothly and with minimum effort, according to Kavathekar [12]. Unlike competitive transfer devices (ball transfers, swivel casters, etc.) They are often used in small robots. In leagues such as Robocup, many robots use these wheels to have the ability to move in all directions. Plastic Omni Wheels are corrosion resistant and well suited for applications Where dirt, dust and moister may be present. They require no lubrication or field maintenance [7].

Figure 2.7: Different types of Omni wheels [7].

In this project we will use 3.15", 80mm Diameter Omni Wheel, with barrels are made of plastic and steel axle pins for strength as shown in Figure 2.8 below. The OMNI Wheels frames have built in keys for coupling multiple units. This arrangement provides maximum mounting flexibility to suit almost any requirement.

Figure 2.8: Plastic Omni wheel use in this project

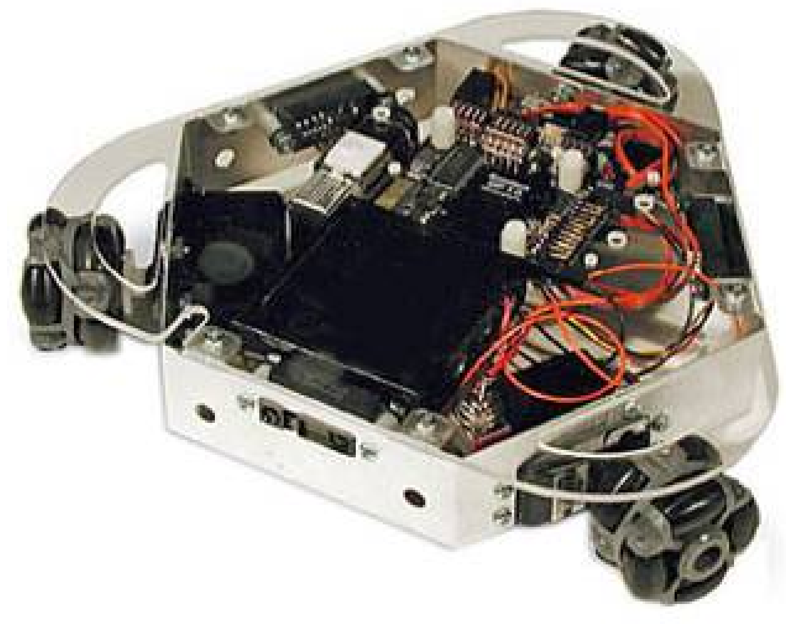


Figure 2.9: Three wheels Omni-Directional Robot. [7]

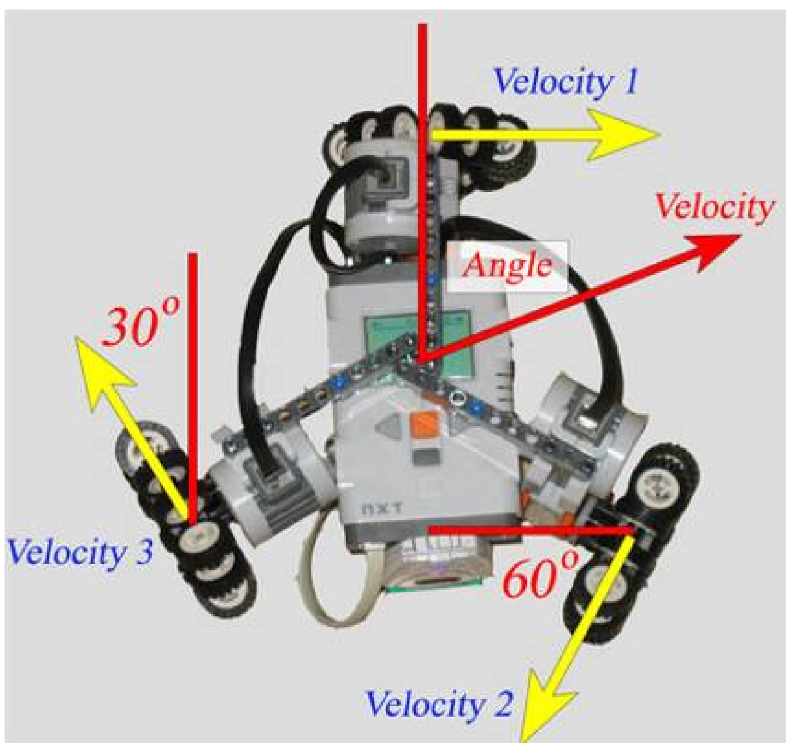


Figure 2.10: Omni robot can move in any direction. [2]

John (2007) has proposed an improved Omni-directional mobile robot using four wheels instead of three wheels as shown in Figure 2.11 below [6]. The reasoning will be explained in the next section.

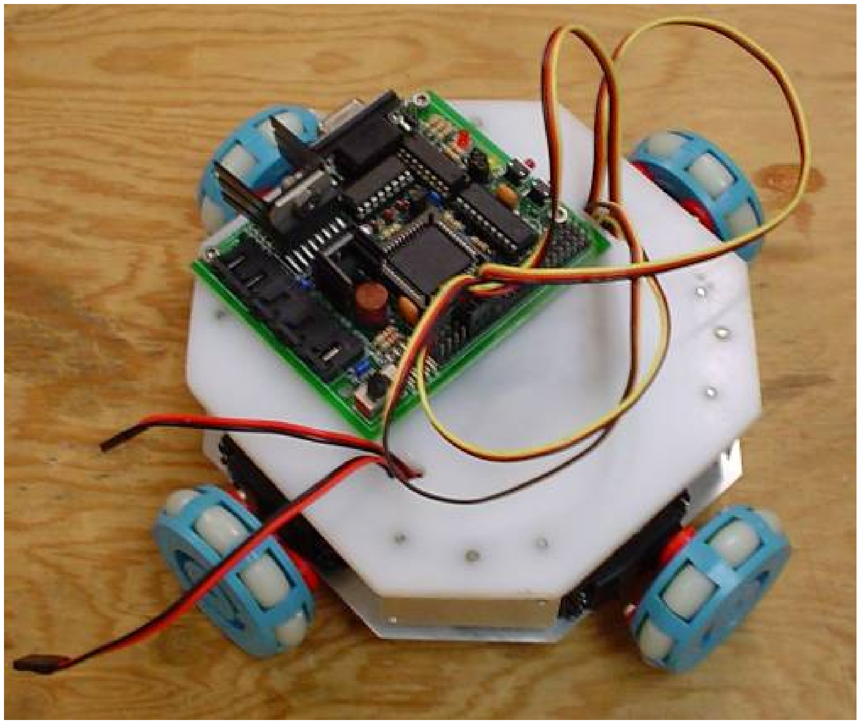


Figure 2.11: Four wheels Omni-robot
using Transwheels™.[6]

2.2.3 Three wheels versus four wheels Omni robot.

A platform employing three Omni wheels in a triangular configuration is sometimes called a Killough platform; so named after Stephen Killough's work with omni-directional platforms at Oak Ridge National Laboratory. Killough's 1994 design used pairs of wheels mounted in cages at right angles to each other and thereby achieved holonomic movement [13]. Most Omni-wheel robots consist of a triangular platform and three wheels. But it is possible, and often better, to use four wheels. There is only one good reason why three wheels are better - three wheels and three motors are cheaper than four of each.

There is however a problem inherent with four wheel vehicles and that is the fact that four points are not guaranteed to be on the same plane. Three points are. If a four wheeled robot encounters uneven terrain, there is a good chance that one of those wheels will not be in contact with the ground. But there are many simple solutions to this. A four-wheel robot can use a rocker-bogey system. Cars use spring shocks. In this project, the author uses flexible motor mounting plus long coupler from motor to wheel to compensate the uneven terrain.

With a three wheels design, there is always at least one wheel not aligned with the direction of motion. This will cause some losses in motion and energy. In case of four wheels Omni-robot, at certain time, two wheels can move while the other two remain idle, without any losses in motion as shown on the right side of Figure 2.12.

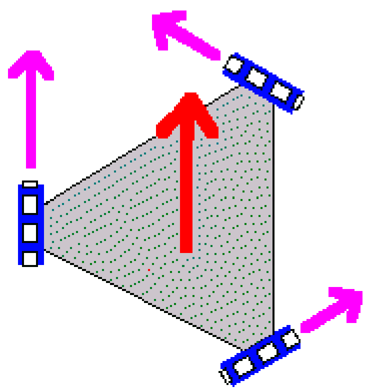


Figure 2.12: Three wheels (left) versus four wheels (right) Omni robot [6].

John (2007) has initiated and suggested the four wheels configuration over three wheels configuration [6]. However, he did not provide proper prove in calculations, neither did he provide control algorithm for such type of robot. In this project, the kinematics of the four wheels configuration will be analyzed and thus provide a proper control algorithm. Detail of how four wheels configuration is more efficient will be discussed in chapter 4, kinematics analysis.

CHAPTER 3

METHODOLOGY

In the introduction, the overview of project's methodology was presented. The methodology consists of identifying needs, establish specification, generate and evaluate concept, fabrication and results [14]. Each part will be discussed in detail in this chapter.

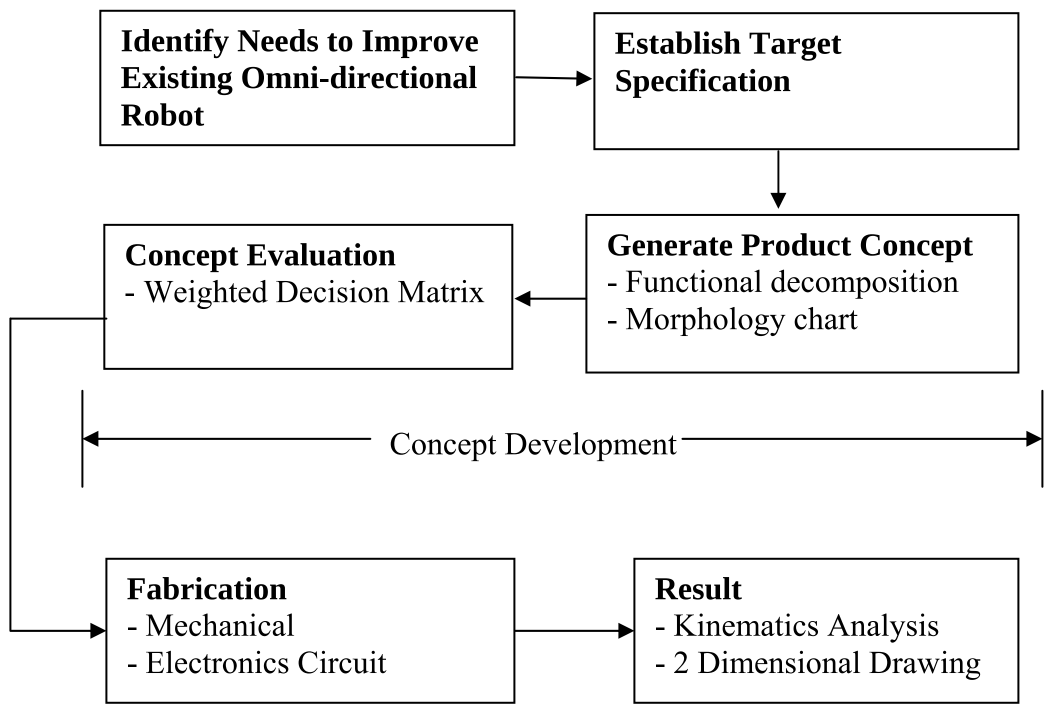


Figure 3.1: Product Design Process.

3.1 Identify Needs

Some study was done on product design and development of a new Omni-directional mobile robot. The need of an improved Omni-directional mobile robot design was gathered by conducting literature review. Although not much was explained for future desirable Omni-directional mobile robots, the basic problems of existing mobile robot were gathered. The needs will form a new measurable specification of an Omni-directional mobile robot in order to compete with current designs.

From the needs of an improved design, it is divided into 4 main parts of the statement. The first part will show the basic typical uses of a mobile robot. From the overall of the customers' statements, there are 3 main basic needs of a mobile robot. The mobile robot should provide a moving platform to support 3 main applications: automated material transport vehicle, surveillance robot and in door applications. From this short search, it was observed that in order to design a proper mobile robot, these following are the basic requirements:

i. Reprogrammable
ii. Robust
iii. Ability to carry load
iv. Low energy consumption
v. High maneuverability
vi. Low cost

3.2 Establish Omni-directional Mobile Robot Specifications

The product design specification (PDS) is the basic control and reference document for the design and manufacture of the product. The PDS is a document which contains all of the facts related to the outcome of the product development. From the search, a proper set of specification is defined in order to finalize the process of establishing the customer needs and wants. Each of the specification will be prioritized and cast them into a technical framework so that design concept can be established. Listed below are elements that are to be found in preliminary of a new concept Omni-directional mobile robot.

<u>Product title</u>

- Omni-directional mobile robot

Purpose

- Mobile robot that is highly reliable and maneuverable to move with ease in any confined space.

Challenge

- Will compete against the conventional wheeled configuration and current Omni-directional mobile robot.

Need for product

- Internet search has shown customer interest in new features. Most of customers expressed willing to buy an improved product. This business strategy is to produce a better product with lower cost to fulfill variety type of customers.

Functional performance

- Can move freely in any direction at any instance
- Can move straight while spinning about itself
- Allow to be reprogrammed in short amount of time with ease
- Move at slow speed compare to human's walking speed
- Able to move on variety of flat surfaces.

Physical requirement

- Standard size measurement for typical in door robot applications.
- Shape limited to circular or near circular to minimize collision while moving.
- Using light material to reduce weight.

Life-cycle issues

- Motor, coupler, wheels, electronics circuit must be able to withstand 2,000 hours between any major maintenance intervals (8 hours/day, for 250 days/year).

3.3 Concept Generation

3.3.1 Decomposition of mobile robot into subassemblies

Based on the basic requirements, the overall project has been decomposed into three sub-systems, as shown in table 3.1 below.

Table 3.1: Decomposition of mobile robot sub-systems

Sub-systems	Components	Features of components
Mechanical Assemblies	Body	Stiff, light weight, small area but provide enough space for electronic circuit
	Frames	Stiff, light weight, easy to assemble
	Joints	Strong, easy to assemble, easy to disassemble
	Motor holders	Strong, easy to assemble, easy to disassemble
	Motor	Provide sufficient torque and rpm
	Transmission	Strong, easy to assemble, easy to disassemble
	Omni-wheels	Good traction barrels, low friction in barrels' axis
Electronic Circuits	Circuit board	Low noise, easy to solder, line width sufficient for high current
	Micro-controller	Enough computation speed, high noise resistance, easy to program, enough I/O
	Motor driver	Able to change direction, power, low noise, fast response, low power consumption
	Power supply for motor	Provide enough power for continuous operation and safe
	Power supply for micro-controller	Provide enough power for continuous operation and safe
Programs	Motor control	Fast, low memory requirement, easy to read, easy to change
	Input/ Output control	

3.3.2 Decomposition of Omni-mobile robot sub-systems into several concepts

Table 3.2 below shows the concepts generated for each component. This step is to find as many concepts as possible which can provide each function identified in the decomposition.

Table 3.2: Concepts of mobile robot sub-system components

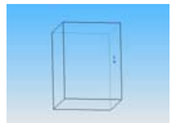
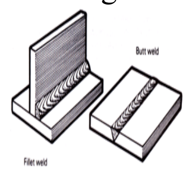
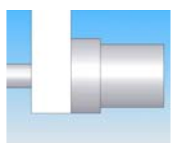
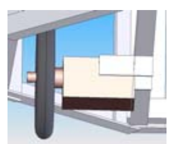
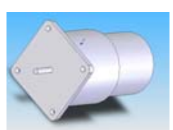
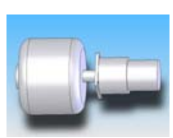
Sub-systems	Components	Concepts
Mechanical Assemblies	Body	- Rectangle shape - Square shape - Hexagonal shape - Round shape
	Joints	- Using bolts and nuts - Using rivet - Using Welding
	Frames	- L bar - Hollow bar - Flat bar - Round bar
	Motor holders	- Vertical - Horizontal
	Motor	- DC motor - Stepper motor - Servo motor
	Transmission	- Direct connect motor and wheel - Connect through pulleys and belts - Connect through spur gears
	Wheels	- Omni-wheels - Trans-wheels - Mecanum wheels
Electronic Circuits	Circuit board	- Printed circuit board - Bread board
	Micro-controller	- Microchip PIC - Intel's micro-controller 8051 - Motorola
	Motor driver	- Integrated circuit H-bridges - MOSFETs - Relays
	Power supply for motor	- Alternating Current (AC) 220V - Direct Current (DC) 6V, 9V or 12V
	Power supply for micro-controller	- DC 6V or 9V

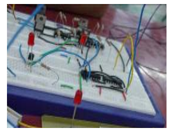
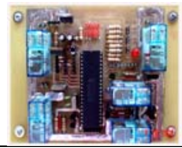
Programs	Motor control	- Using C language - Using assembly language
	Input/ Output control	

3.3.3 Morphology Chart

According to David (2003), morphological method uses the function identified to foster ideas. It consists of two steps, the first step is to provide as many concepts for each identified component in the decomposition as possible. The second step is to combine these individual concepts into overall concepts that meet all functional requirements [14]. The morphology chart is used to represent the morphological method as shown in Table 3.3 below.

Table 3.3: Morphology chart

Sub-systems	Components	Concept 1	2	3	4
Mechanical Assemblies	Body shape	Rectangle 	Square 	Hexagonal 	Round 
	Joints	Bolts and nuts 	Rivet 	Welding 	
	Frames	Flat bar 	L bar 	Rectangle hollow bar 	Round rod 
	Motor holders	Vertical 	Horizontal 		
	Motor	DC motor 	Stepper motor 	Servo motor 	
	Transmission	Direct connect 	Belts and pulleys 	Spur gear 	
	Wheels	Omni-wheel 	Trans-wheel 	Mecanum wheel 	Conventional wheel 

Electronic Circuits	Circuit board	Bread board 	Printed circuit board 		
	Micro-controller	Microchip PIC 	Intel 8051 	Motorola 	
	Motor driver	IC H-bridge 	MOSFET 	Relay 	
	Power supply for motor	AC 220V	DC 6V	DC 9V	DC 12V
	Power supply for micro-controller	DC 6V	DC 9V		
Programs	Control motor	C language	Assembly language		
	Inputs/ Outputs				

After establishing the Omni-directional mobile robot specification, the concept generation will be the next step in designing Omni-directional mobile robot. The detail literature review and clear problem definition will help to keep focus on critical problem of Omni-directional mobile robot. The morphology chart above shows the decomposition as well as concepts for individual components. All ideas are listed above, and by combination of those different component will result in producing several new concepts of Omni-directional mobile robot.

3.3.4 Concept 1

From the morphology chart, concept 1 is developed by combining different components. These components are rectangular body shape using L bars, 2 conventional drive wheels, with front and back offset casters, horizontal motor holder as shown in Figure 3.2 below. Concept 1 also uses welding at joints to connect L bars. This concept will enable the robot to rotate about itself. However, due to rectangular shape, the robot will face many problems due to collide with the surroundings.

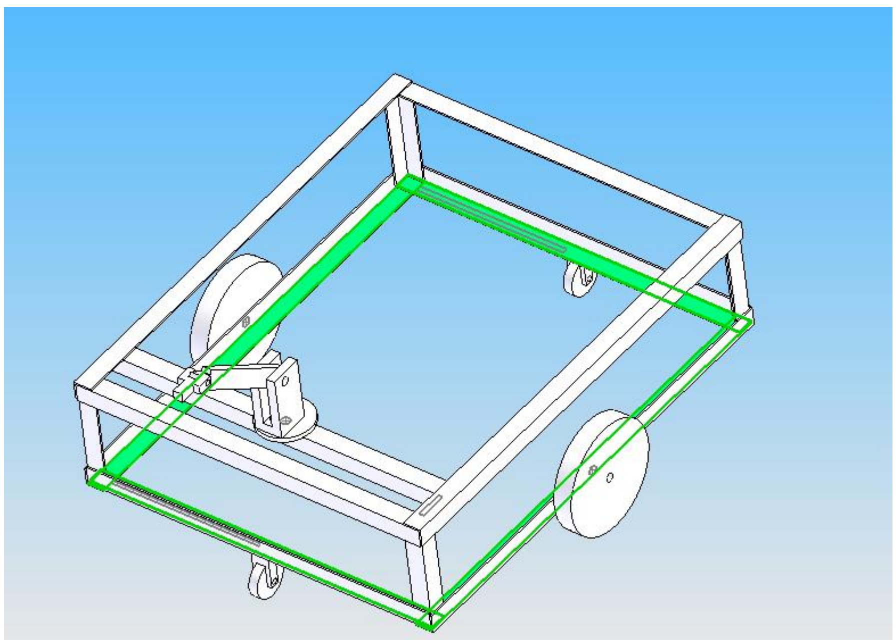


Figure 3.2: 3D Concept 1

Description

1. Conventional wheel with offset castors
2. Servo motor
3. Horizontal motor holder
4. Welded joints
5. Rectangle body shape
6. Using L bars for frames
7. Using pulleys and belt for power transmission

3.3.5 Concept 2

Figure 3.3 shows concept 2 is a combination of different components from concept 1. Concept 2 is derived with hexagonal shape, and the wheels have been design inside the body to reduce the clash with the surrounding objects. Concept 2 uses bolts and nuts at joints to connect the bars. This concept can provide a zero turning radius, however not yet achieve Omni-directional ability. The wheels inside robot's frame however prevent the wheels to move up-down to compensate the slight uneven of the surface.

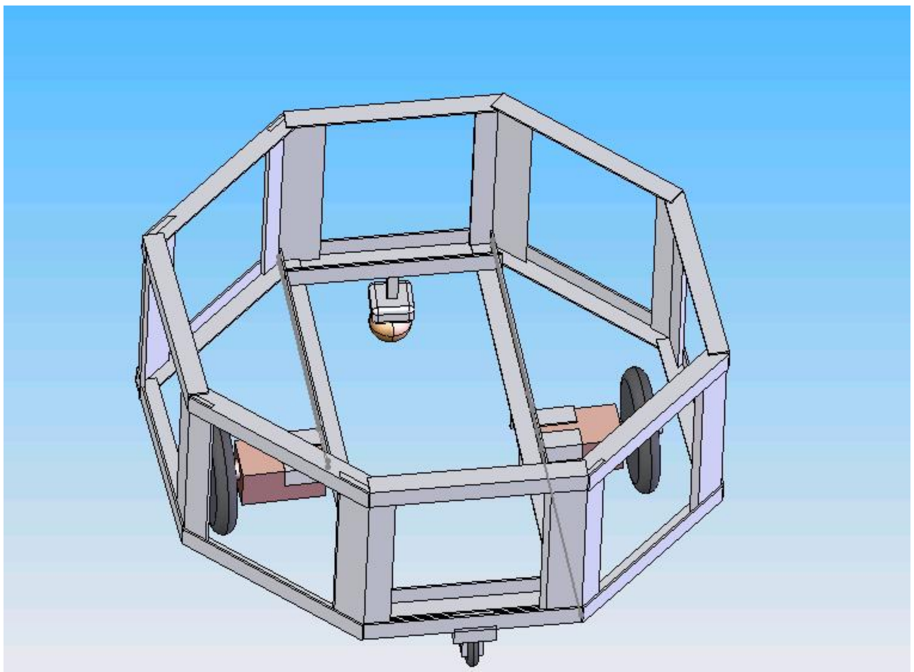


Figure 3.3: 3D model of Concept 2

Description

1. Conventional wheel with ball castors
2. Stepper motors
3. Horizontal motor holder
4. Using bolts and nuts at joints
5. Hexagonal body shape with wheels inside body
6. Using L bars for frames
7. Using spur gear for power transmission

3.3.6 Concept 3

Concept 3 as shown in Figure 3.4 below is the design that uses Omni-directional wheels. This concept is the combination of hexagonal body shape with wheels outside body, horizontal motor holder, and direct transmission from motor to wheels. This concept using four Omni-wheels 90 degrees offset with each other.

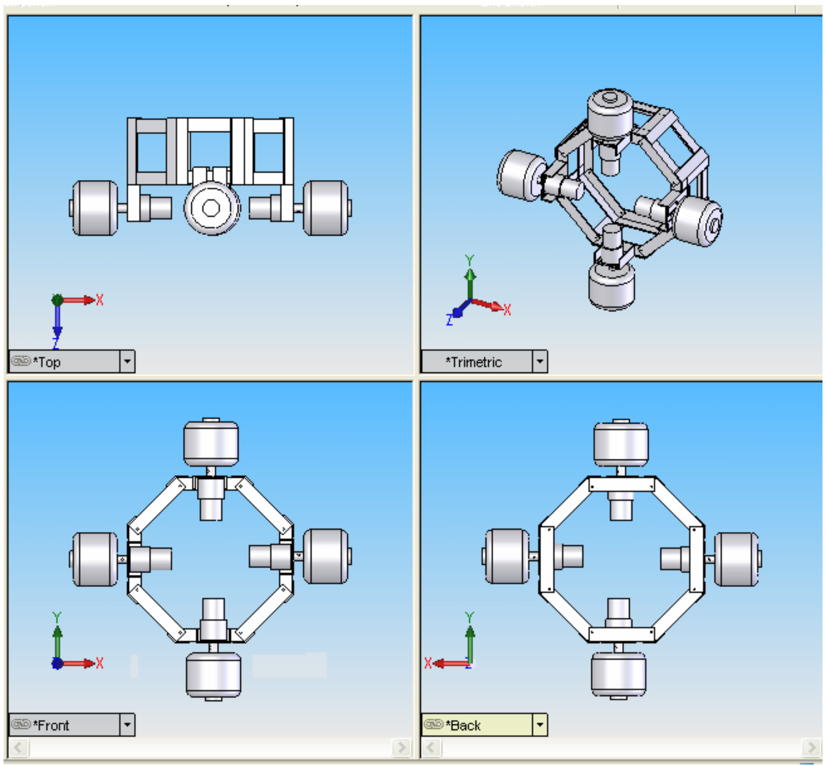


Figure 3.4: 3D model of concept 3 using Omni-wheels.

Description

1. Four Omni wheels 90 degrees offset with each other
2. DC geared motors
3. Vertical motor holder
4. Using rivets at joints
5. Hexagonal body shape with wheels outside body
6. Using L bars for frames
7. Using direct connect through coupling for transmission

3.4 Concept Evaluation

At this stage, justification of choosing which concepts to develop into finished design is essential. A good method to judge on the most promising design concept at the concept stage is Weighted Decision Matrix. A weight decision matrix is a method of evaluating competing concepts by ranking the design criteria with weighting factor and scoring the degree to which each design concepts meets criterion. In doing this, it is necessary to convert the value that is obtained for different design criteria into a consistent set of values. The simplest way of dealing with design criteria is expressed in a variety of ways to use a point scale. A 5-point scale shows in Table 3.4 below is used for this evaluation due to knowledge about the criteria is not very detailed. If more information is obtained, the 11-point scale can be used to provide a better comparison.

Table 3.4: Evaluation scheme for the design objective

5-point scale	Description
0	Inadequate
1	Weak
2	Satisfactory
3	Good
4	Excellent

After getting the 5-point scale of evaluation scheme, the next step is to identify the design criteria. With the existence Omni-directional mobile robot evaluation has been done at early stage of design process, several criteria had been developed and are useful at this stage to evaluate each of the concepts.

Before proceeding to weighted decision matrix final step, each criterion is needed to justify and determine the weighting factors. The weights of the individual category at each component must be added up and the total summation is equal to 1.0 as shown in Table 3.5 below. The decision matrix method in Table 3.6 shows that concept 3 is the best concept among the three, and concept 3 will be chosen for analysis.

Table 3.5: Object table to evaluate in weighted decision matrix

Criteria	Weight
Body shape	0.1
Joints	0.1
Frames	0.1
Motor holders	0.1
Motor	0.2
Transmission	0.1
Wheels	0.3

Table 3.6: Weighted decision matrix

Design criterion	Weight factor	Concept 1			Concept 2			Concept 3		
		Magnitude	Score	Rating	Magnitude	Score	Rating	Magnitude	Score	Rating
Body shape Reduce collision	0.1	Weak	1	0.1	Good	3	0.3	Good	3	0.3
Joints Strong Easy to assemble, disassemble	0.1	Satisfactory	2	0.2	Satisfactory	2	0.2	Good	3	0.3
Frames Strong Easy to assemble, disassemble	0.1	Satisfactory	2	0.2	Satisfactory	2	0.2	Satisfactory	2	0.2
Motor holder Strong	0.1	Satisfactory	2	0.2	Satisfactory	2	0.2	Good	3	0.3
Motor Torque Speed	0.2	Satisfactory	2	0.4	Weak	1	0.2	Good	3	0.6
Transmission Efficiency Easy to assemble, disassemble	0.1	Satisfactory	2	0.2	Good	3	0.3	Good	3	0.3
Wheels Omni-directional movement	0.4	Satisfactory	1	0.4	Satisfactory	2	0.8	Good	3	1.2
Total	1.0	Total : 1.7			Total : 2.2			Total: 3.2		

3.5 Electronics Circuit Development

This process develops the control and drive circuit to control the robot. The control circuit consists of 1 Programmable Interface Controller (PIC) 18F4431 and 6 modules of LMD18200 H-Bridge motor driver. The circuit also provides over 30 Input/Output channels sufficient for all the requirements. An additional feature of this circuit is LCD display, which provides interface between robot and human for ease of control.

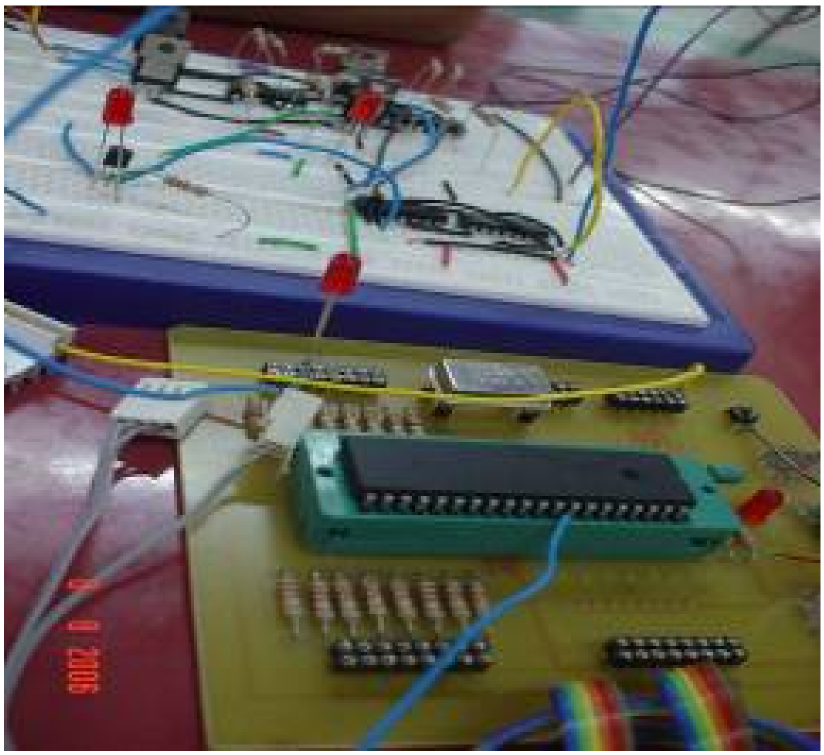


Figure 3.5: Test circuit using bread board.

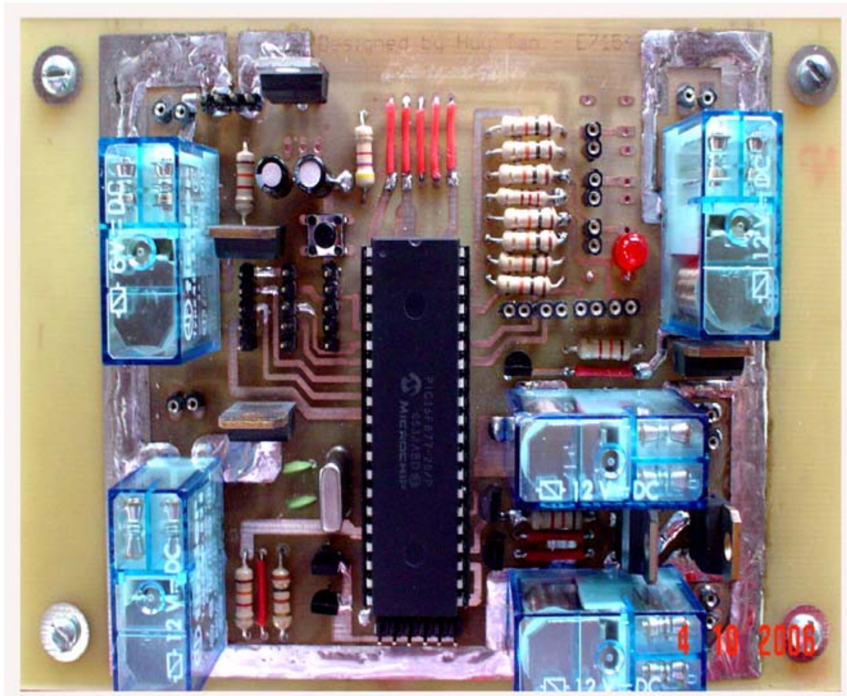


Figure 3.6: PCB circuit using relays to control motors.

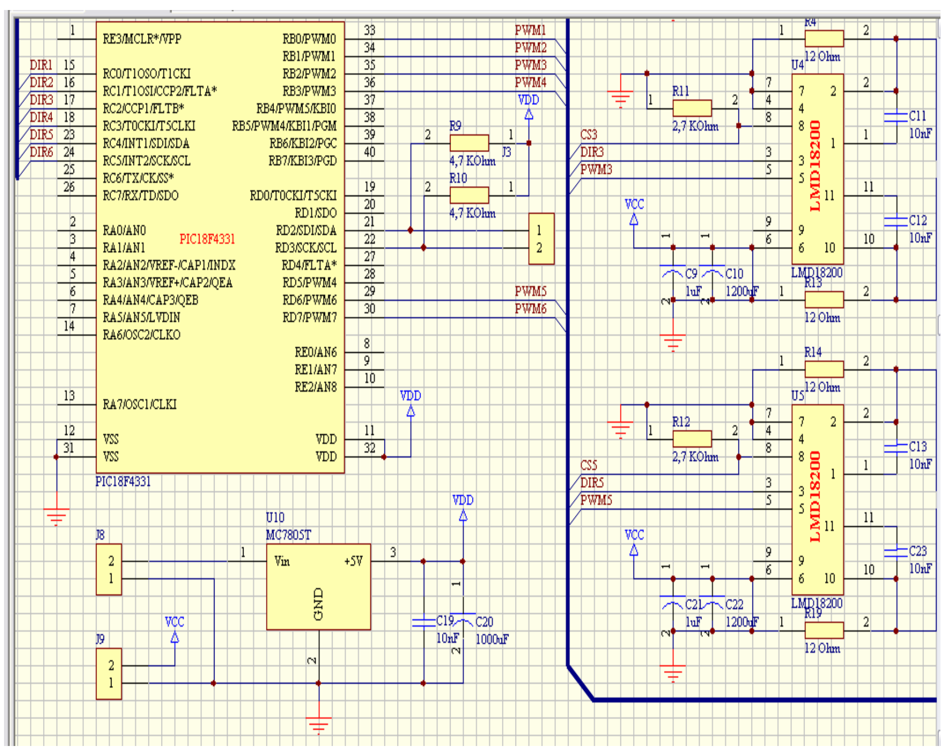


Figure 3.7: Schematic of electronic circuit using PIC 18F4431 and LMD18200.

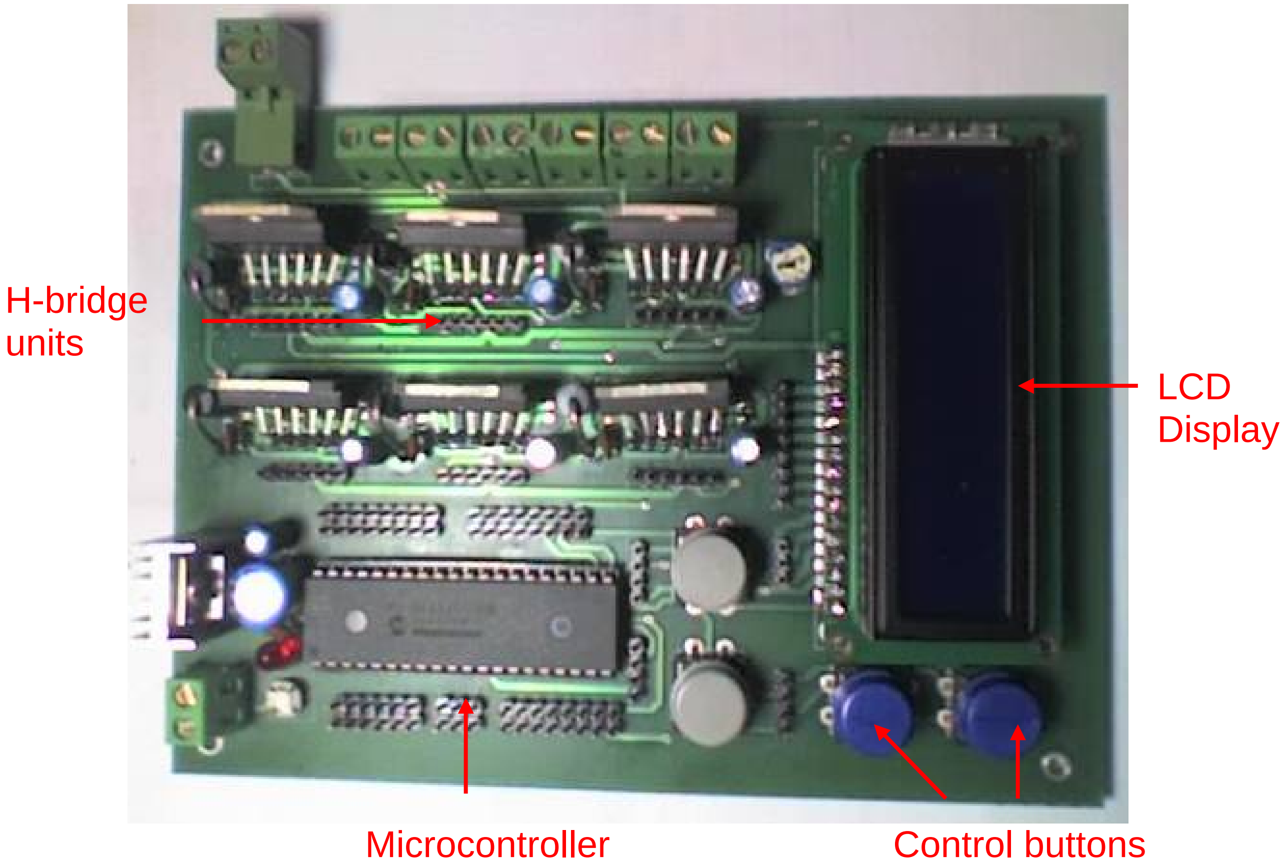


Figure 3.8: Control and drive circuit of the Omni Robot.

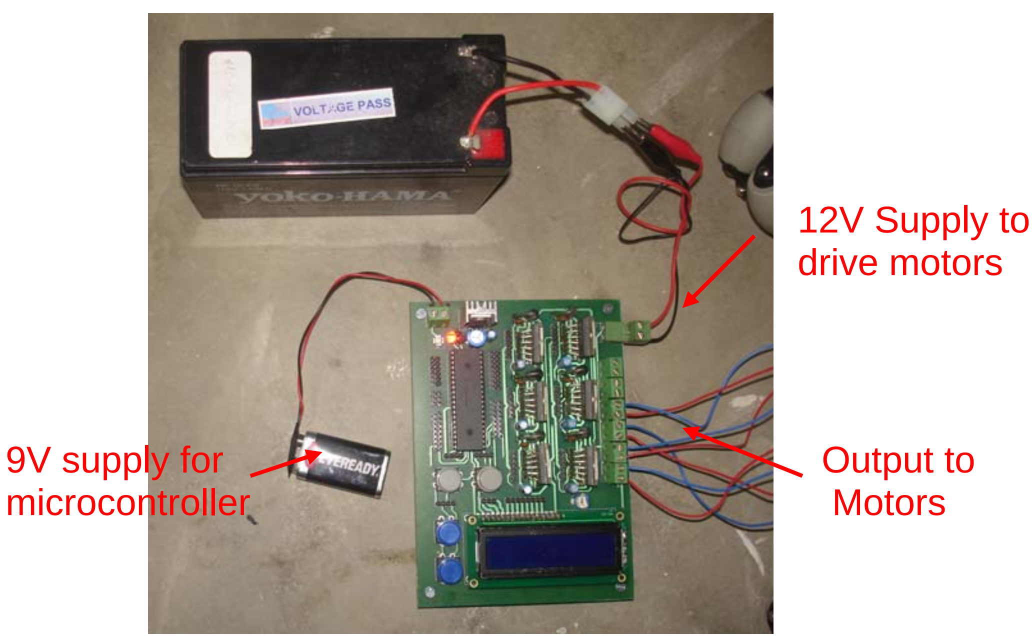


Figure 3.9: Control circuit after connect to battery.

3.5.1 Microchip's 18F4431 Micro-Controller

Microchip's Programmable Interface Controller (PIC) is the main controller being used in this project. This micro controller is chosen because of high immune to noise compare to other brand such as Intel's 8051, Atmel's AVR etc. plus a large programming community and technical support from Microchip. And it has enough features to control a small robot as shown in table 3.7 below:

Table 3.7: Main Features of PIC 18F4431 [27].

Parameter Name	Value
Program Memory Type	Flash
Program Memory Size (Kbytes)	8
RAM	768
Data EEPROM	256
I/O	36
Power Control PWM Module	8
Motion Feedback Module w/ Quadrature Encoder Interface	2
200Ksps ADC Module	10
Internal Oscillator	8MHz
Self-Programming	
Max Speed	40 MHz

3.5.2 7805 Voltage Regulator

The 7805 series of three-terminal positive voltage regulators employ built-in current limiting, thermal shutdown, and safe-operating area protection which make them virtually immune to damage from output overloads. With adequate heat sinking, they can deliver in excess of 0.5A output current. Typical applications would include local (on-card) regulators which can eliminate the noise and degraded performance associated with single-point regulation.

3.5.3 LMD18200 H-bridge

H-bridge is an electronic circuit which enables DC electric motors to be run forwards or backwards. These circuits are often used in robotics. H-bridges are available as integrated circuits, or can be built from discrete components.

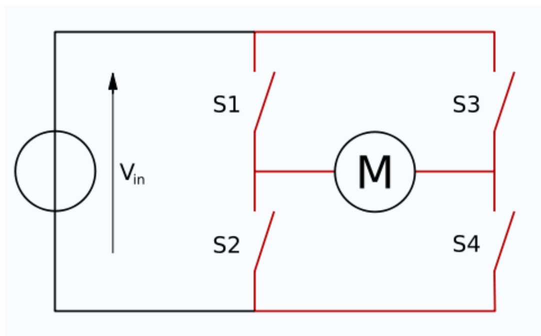


Figure 3.10: Representation of an H-Bridge circuit to control motor (M) [17].

The term "H-bridge" is derived from the typical graphical representation of such a circuit. An H-bridge is built with four switches (MOSFETs or Relays). When the switches S1 and S4 (according to the above Figure 3.11) are closed (and S2 and S3 are open) a positive voltage will be applied across the motor. By opening S1 and S4 switches and closing S2 and S3 switches, this voltage is reversed, allowing reverse operation of the motor. Using the nomenclature above, the switches S1 and S2 should never be closed at the same time, as this would cause a short circuit on the input voltage source. The same applies to the switches S3 and S4. This condition is known as shoot-through.

The H-Bridge arrangement is generally used to reverse the polarity of the motor, but can also be used to 'brake' the motor, where the motor comes to a sudden stop, as the motors terminals are shorted, or to let the motor 'free run' to a stop, as the motor is effectively disconnected from the circuit. The following Table 3.2 summarizes operation.

Table 3.8: State of bridges and result in motor's operation.

S1	S2	S3	S4	Result
1	0	0	1	Motor moves right
0	1	1	0	Motor moves left
0	0	0	0	Motor free runs
0	1	0	1	Motor brakes

The LMD18200 is a 3A H-Bridge designed for motion control applications. The device is built using a multi-technology process which combines bipolar and CMOS control circuitry with DMOS power devices on the same monolithic structure. Ideal for driving DC and stepper motors; the LMD18200 accommodates peak output currents up to 6A. An innovative circuit which facilitates low-loss sensing of the output current has been implemented. [17]

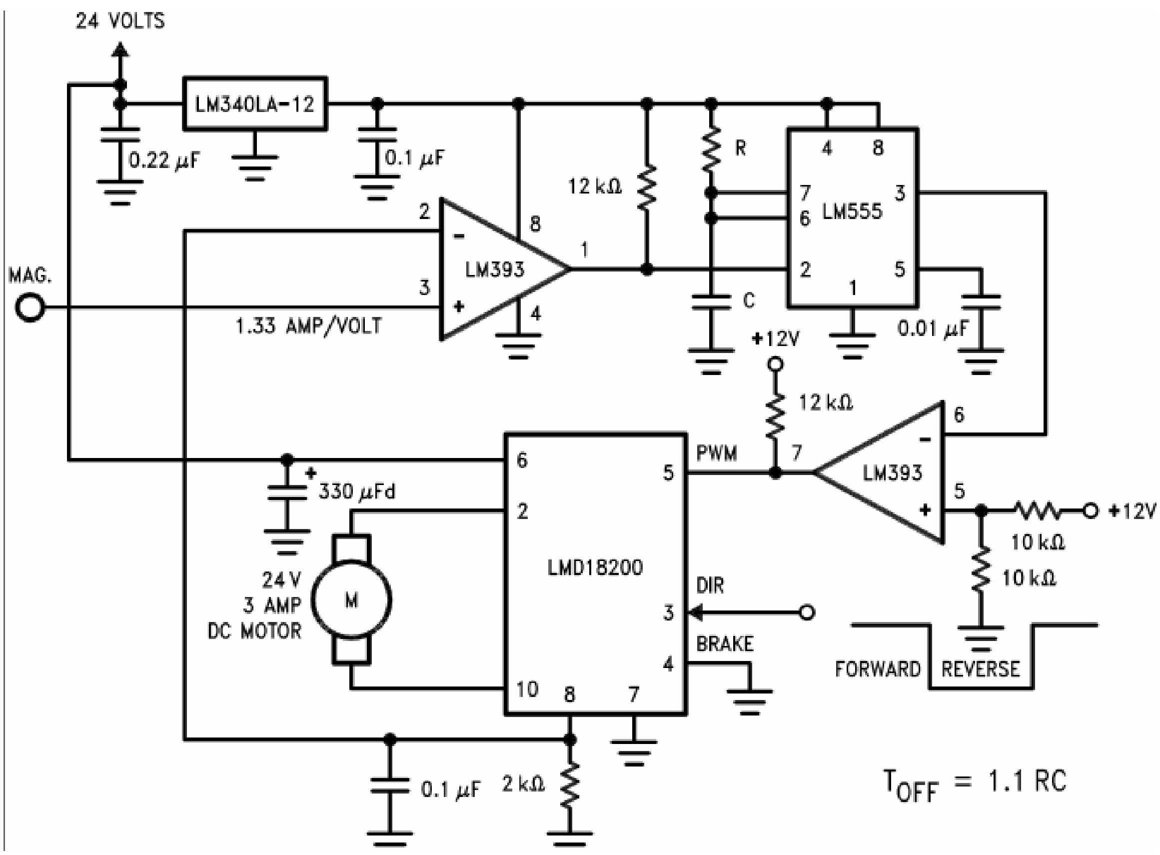


Figure 3.11: Typical layout of LMD18200 circuit. [17]

National Semiconductor’s LMD18200 H-Bridge has the following features [17]:

•Delivers up to 3A continuous output

•Operates at supply voltages up to 55V

•Low R_{DS}(ON) typically 0.3Ω per switch

•TTL and CMOS compatible inputs

•No "shoot-through" current

•Thermal warning flag output at 145°C

•Thermal shutdown (outputs off) at 170°C

•Internal clamp diodes

•Shorted load protection

•Internal charge pump with external bootstrap capability

3.6 Control Concept Using Pulse Width Modulation

Pulse width modulation (PWM) is a technique for controlling analog circuits with a processor's digital outputs. PWM is employed in a wide variety of applications, ranging from measurement and communications to power control and conversion.

By controlling analog circuits digitally, system costs and power consumption can be drastically reduced. Many microcontrollers already include on-chip PWM controllers, making implementation easy. PWM is a way of digitally encoding analog signal levels. Through the use of high-resolution counters, the duty cycle of a square wave is modulated to encode a specific analog signal level. The PWM signal is still digital because, at any given instant of time, the full DC supply is either fully on or fully off. The voltage or current source is supplied to the analog load by means of a repeating series of on and off pulses. The on-time is the time during which the DC supply is applied to the load, and the off-time is the period during which that source is switched off. Given a sufficient bandwidth, any analog value can be encoded with PWM.

Figure 3.12 shows three different PWM signals. These three PWM outputs encode three different analog signal values, at 10%, 50%, and 90% of the full power. If, for example, the supply is 9V and the duty cycle is 10%, a 0.9V analog signal results.

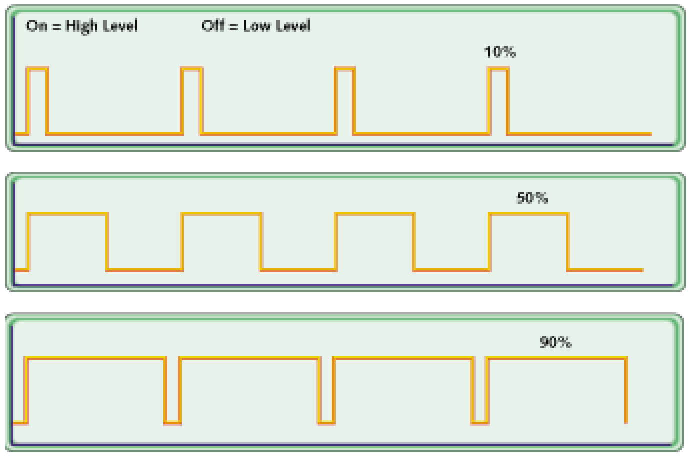


Figure 3.12: PWM signals of varying duty cycles

3.7 Electronics Tools

Figure 3.13 shows the programmer for Microchip PIC 18F4431. This programmer has ability to program and debug most of Microchip's micro-controllers.

Figure 3.13: Microchips' In Circuit Debugger 2 (ICD2)

3.8 Mechanical Assembly Fabrication Process

After the best concept was selected, the design concept moves to fabrication stage, where the mechanical assembly was manufactured. Table 3.9 shows the process plan for fabrication.

Table 3.9: Process plan for fabrication.

Process number	Process name	Raw material	Machine	Tools	Estimated time (hours)
1	Cutting horizontal frames	Aluminum L bars	Automatic saw	Saw blade	2
2	Drill holes for riveting	Aluminum L bars	Bench drill	Drill bit	7
3	Cutting vertical frame	Aluminum flat bars		Scissor	3
4	Bending vertical frames	Aluminum flat bars	Bench machine	Vernior Caliper	2
5	Drill holes for riveting	Vertical frames	Bench drill	Drill bit	2
6	Riveting frames	Aluminum bars	Handheld rivet gun	Rivets	4
7	Cutting motor holder	Aluminum L bars	Automatic saw	Saw blade	0.5
8	Drill holes for riveting	Aluminum L bars	Bench drill	Drill bit	0.5
9	Riveting motor holder	Aluminum bars	Handheld rivet gun	Rivets	0.5
10	Lathe coupling	30mm Aluminum solid rod	Lathe machine	Cutting tools, Vernior caliper	10
11	Drill holes for screw	Coupling	Bench drill	Drill bit	0.5
12	Tapping internal threads	Coupling	Tap	Clamp table	2
13	Assemble Omni wheels	Omni wheels		Allen keys	1
Total estimated time (hours)					35

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Omni-directional Robot Prototype

The 3D-modeling and the simulation can be done successfully using 3D CAD software. The software used in this project able to perform several different operations, from 3D design, weight and moment of inertia measuring, and simulation. By using CAD software in the design and simulation stage, the project can save time and cost effectively in the fabrication and testing stages. For functional tests, the robot will be tested on flat hard surface such as concrete, flat soft surface as carpet, and uneven surfaces. The test results will indicates whether the robot meets expected performance during the designing stage. All results from this project will be used as the platform for future research in mobile robot at UTP. Figure 4.1, 4.2 shows the picture of the completed prototype, with integrated circuit. Table 4.1 shows the main functions of the Omni-robot, which satisfy the customers' need addressed in the objectives.

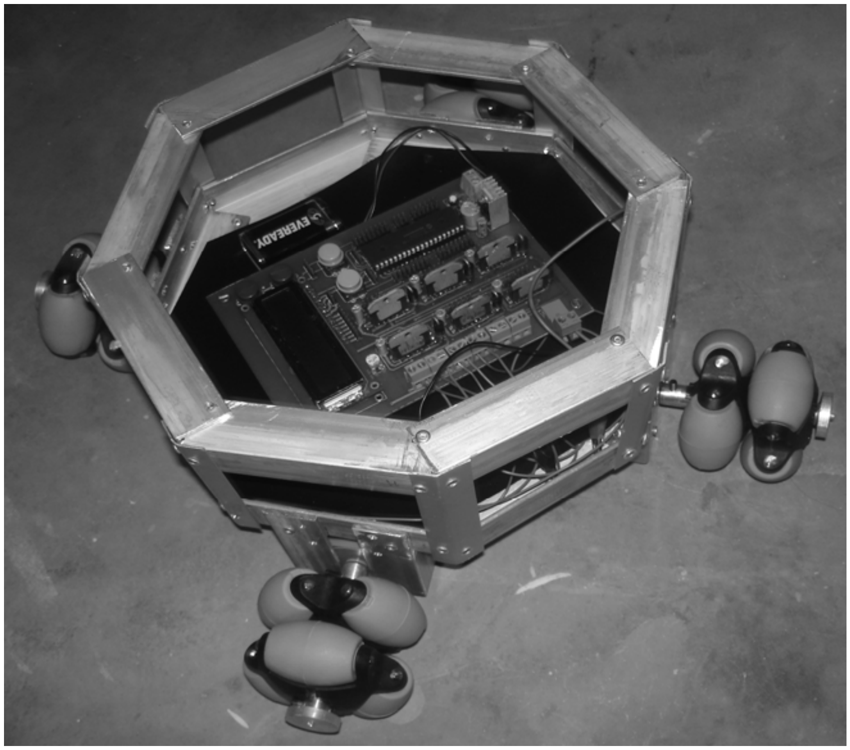


Figure 4.1: Omni-robot trigonometric view

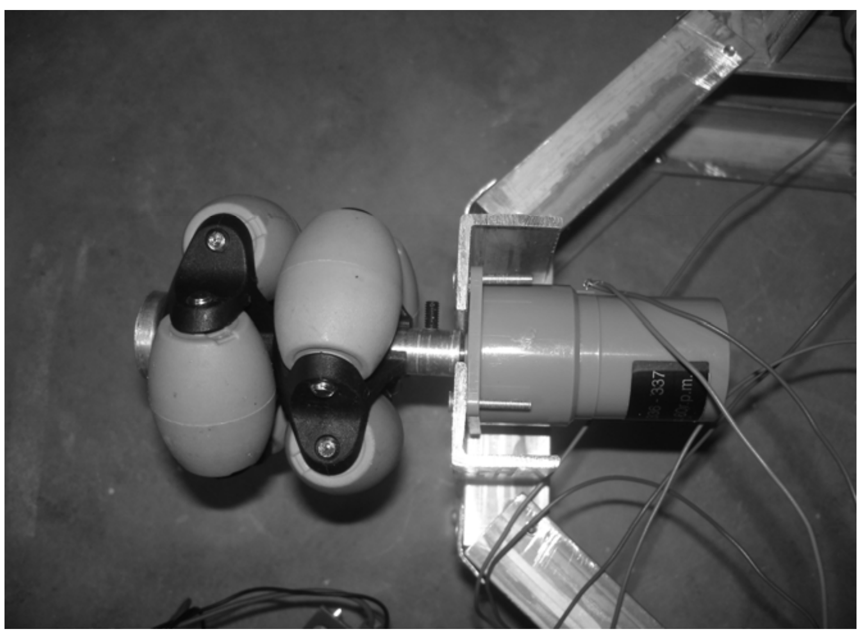


Figure 4.2: Motor connect to wheel through coupler

Table 4.1: Characteristic of Omni-directional Mobile Robot

Number of wheels	4
Degrees of freedom	2 (Omni-directional)
Motors	4 (12VDC)
Robot Length	310 mm
Frame shape	Octagonal
Robot width	310 mm
Controller	Microchip's PIC 18F4431
Maximum load	1 kg
Maximum Speed	0.5 m/s

4.2 Analysis of Kinematics

Robot kinematics is the study of the motion (kinematics) of robots. In a kinematics analysis the position, velocity and acceleration of all wheels are calculated without considering the forces that cause this motion. The relationship between motion, and the associated forces and torques is studied in robot dynamics [18, 19].

Robot kinematics is mainly of the following two types: forward kinematics and inverse kinematics. Forward kinematics is also known as direct kinematics. In forward kinematics, the arrangement and rotational angle of each wheel of mobile robot is given, and we have to calculate the position of the robot at any time. In inverse kinematics, the wheel arrangement and position of robot is given, we have to calculate the individual wheel rotational angle [26].

According to Gregory (2000), mobile robot kinematics also can be divided into differential drive, synchronous drive, steered wheels, Ackerman steering, and complex wheels kinematics [26]. In case the robot using complex (Omni) wheels such as in this project, due to the slip (caused by rotation of tangential barrels) is essential for the overall motion of the Omni robot, the inverse kinematics matrix method is normally unsolvable. The reason inverse kinematics method is unsolvable is because there are four (4) wheels with slippage and there are only three pose parameters x, y for position and θ for direction of any robot on x-y plane. Further more, the initial intention of creating Omni-directional is to create a robot that can move in any direction without prioritized movement direction. Which means only x and y coordination is important for the robot.

Based on this method, we will consider two types of drive that can be applied into this project's Omni-directional mobile robot are differential drive and complex (Omni) wheels kinematics.

4.2.1 Differential Drive

Differential drive is one of the simplest possible drive mechanism for a ground-contact mobile robot [26]. As shown in Figure 4.3 below, a differential drive robot normally consists of two wheels mounted on a common axis controlled by separate motors. Under differential drive, for each of the two drive wheels to exhibit rolling motion, the robot must rotate about a point that lies on the common axis of the two drive wheels. By varying the relative velocity of the two wheels, the point of this rotation can be varied, and different trajectories chosen.

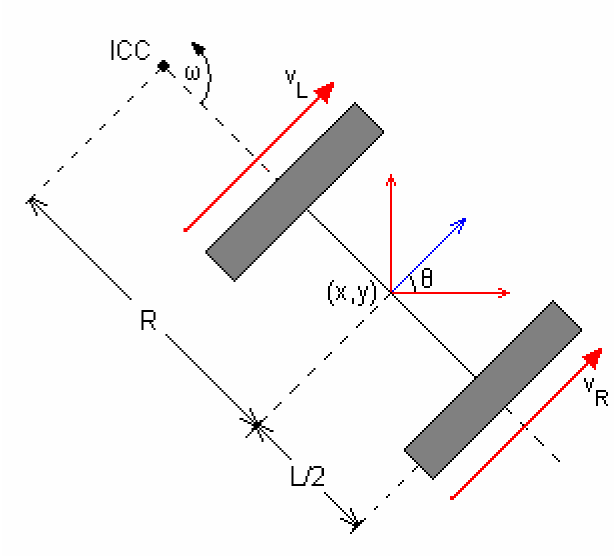


Figure 4.3: Differential drive kinematics.

At each instant, the point at which the robot rotates must have property that left and right wheels follow a path that moves around the instantaneous center of curvature (ICC) at the same angular rate ω [26]

$$\omega(R + L/2) = v_r \quad (4.1)$$

$$\omega(R - L/2) = v_l \quad (4.2)$$

where L is the distance along the axle between the centers of the two wheels, the left wheel moves with velocity v_l along the ground and the right with velocity v_r, and R is the distance from the ICC to the midpoint between the two wheels. Solving for R and ω we have:

$$R = [L\,(v_l + v_r)] / [2(v_l - v_r)] \quad (4.3)$$

$$\omega = (v_r - v_l)/L \quad (4.4)$$

In this project, the differential drive method can be applied into control of Omni-robot because it is easy to calculate and faster on an un-obstructed plane. To apply differential drive method into Omni-directional drive, two wheels 1 and 3 acting as drive wheels, while wheels 2 and 4 acting as steering wheels as shown in Figure 4.4.

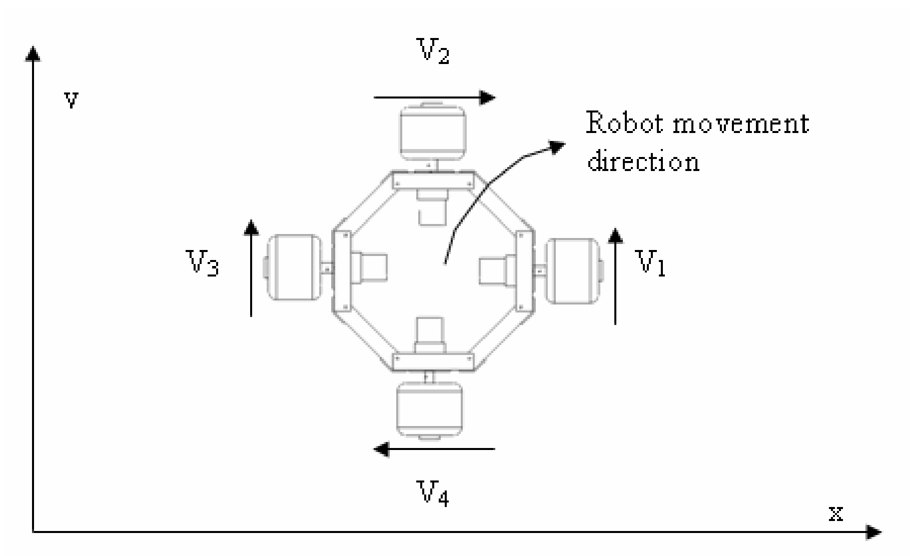


Figure 4.4: Omni-robot using differential drive method.

From the combination of wheels rotation, the Omni-robot is now move in differential drive mode and have trajectory in form of a curve with instantaneous R and ω as follow:

$$R = [L(v_3 + v_1)] / [2(v_3 - v_1)] \quad (4.5)$$

$$\omega = (v_1 - v_3)/L = (v_2 + v_4)/L \quad (4.6)$$

4.2.2 Omni-directional drive

Omni-directional drive is applied to provide robot a free movement in any direction, which means the robot can move in any direction, at any instance. For the four Omni-wheels configuration, the Omni-directional movement can be achieved by combining the rotations of two pair of wheels 1-3 and 2-4 as shown in Figure 4.6.

Wheels pair 2-4 provides x axis motion, and pair 1-3 provides y axis motion, provide condition that wheels 2 and 4 rotate at the same speed, and wheels 1 and 3 rotate at same speed. With the combination of two axis movement, the robot can achieve fully Omni-directional ability. With this type of drive, direction θ will not affect the trajectory of the robot as in differential drive. The robot now moves like a point on x-y plane with x and y velocity components as shown in Figure 4.6.

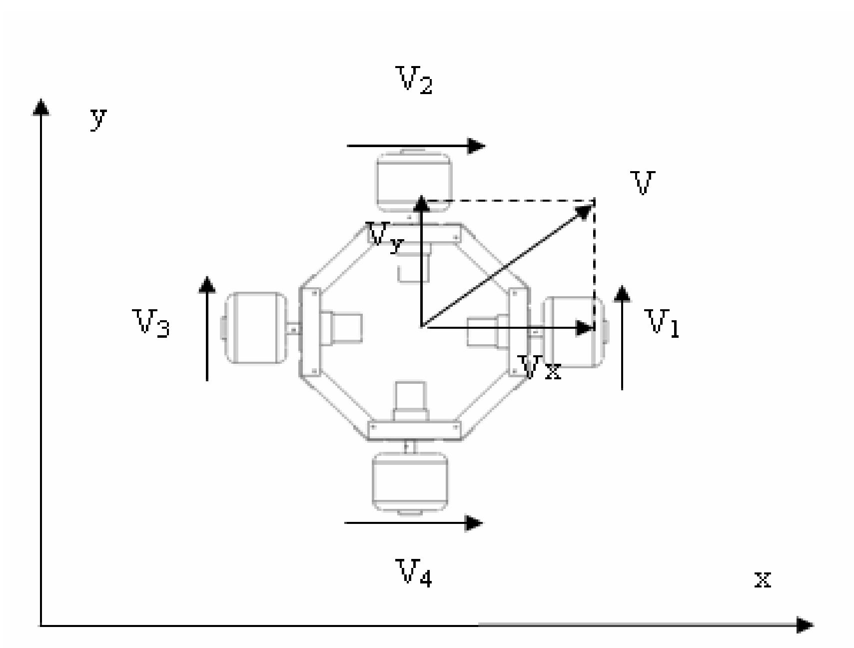


Figure 4.5: Omni-directional drive method.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

During the first semester, background of the study and literature review of the mobile robot has been conducted. The study shows the need of an improved design of Omni-directional mobile robot. The result shows that the fabrication of this robot can be done using current technology and equipment at UTP. Morphology chart and weighted decision matrix have been done to select the best conceptual design for analysis and fabrication.

The kinematics analysis was done and proves that the mobile robot can move in any direction (Omni- direction). Fabrication was carried out to produce a prototype of an Omni-directional mobile robot. However, there are still many development can be applied for future developments, such as integrate camera for path-planning algorithm.

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