DESIGN AND FABRICATION OF WIRELESS OPERATED PAINTBALL ROBOT FOR MIROC 2014 COMPETITION

By

ZULYADAIN BIN ISHAK

FINAL PROJECT REPORT

Submitted to the Department of Electrical & Electronic Engineering
in Partial Fulfilment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronic Engineering)

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

DESIGN AND FABRICATION OF WIRELESS OPERATED PAINTBALL ROBOT FOR MIROC 2014 COMPETITION

by

Zulyadain bin Ishak

A project dissertation submitted to the
Department of Electrical & Electronic Engineering
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
Bachelor of Engineering (Hons)
(Electrical & Electronic Engineering)

Approved:

____

(Dr. Mohd. Haris Bin M. Khir)
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

December 2013

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.

Zulyadain Bin Ishak

ABSTRACT

The purpose of this project is to design and fabricate a wireless operated paintball robot for MIRoC 2014 competition. The previous paintball robot built has some technical issues, in which the driving mechanism applied are less maneuverable and it has bulky chassis design which increases the chance of being hit by another robot in the competition. In this project, the focus is to perform improvements on the paintball robot in terms of its driving mechanism and the chassis based on previous paintball robot. For the driving mechanism, Mecanum driving mechanism has been applied to the robot. The Mecanum driving mechanism mixer circuit is designed and simulated using Multisim and fabricated for application in the field. For the chassis improvement, the new designed chassis has lower height which reduces the chance of being hit. The design was made using SketchUp Pro. The performance of the robot is determined by its maneuverability and simplicity of the control in reference to its predecessors. The results show that the fabricated robot has achieved higher maneuverability rate and have smaller chassis size, which is advantageous in the competition later. In conclusion, the project is successful as it has achieved its main objectives stated earlier. In the future, the result of this project can be replicated to be used for other purpose in other fields.

ACKNOWLEDGEMENTS

First of all, all praise to The Almighty, Allah s.w.t because with His blessing, I am able to complete my project with no major problems. Next, i would like to thank my FYP supervisor, Dr. M.Haris Bin Md. Khir for his guidance and assistance provided during the course of this project. Not forgotten, the coordinators of FYP as they have provided much assistance and resources in assisting the students in completing the projects assigned.

I also wanted to say thanks to the members of PETROBOTS, UTP especially to the members of MIROC for their assistance, especially on the manufacturing and fabrication aspect of my project.

Not to forget, thank you for the support from all my family and friends in both physical and mental support. As without them, I may not able complete this project.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

UniMAP - Universiti Malaysia Perlis
MIRoC - Malaysian International Robotic Competition
DC - Direct Current
BLDC - Brushless DC Motor
CAD - Computer Aided Design
GHz - Gigahertz
FW - Forward
RW - Reverse
ROT-L - Rotate Left
ROT-R - Rotate Right
STR-L - Strafe Left
STR-R - Strafe Right
DIA-FWL - Diagonal Forward-Left
DIA-FWR - Diagonal Forward-Right
DIA-RWL - Diagonal Reverse-Left
DIA-RWR - Diagonal Reverse-Right

CHAPTER 1

INTRODUCTION

This chapter provides an overview on the project background, the problem statement, the project's objective and its scope of study, as well as the project's feasibility.

1.1 Background of Study

A paintball robot competition is a competition that based on an actual paintball game. In Malaysia, this kind of competition has been organized by Universiti Malaysia Perlis (UniMAP) under the name of Malaysian International Robotic Competition (MiRoC). The objective of this competition is to achieve victory by placing flags at the rival's base or eliminating the rival's robots. In this competition, each robot is equipped with a paintball gun mounted on the robot's chassis and the full system is controlled wirelessly by human operators.

In a paintball robot design, there are many criteria to be considered during the development stage such as the driving mechanism, the robot's control system of the paintball gun trigger and the flag gripper, as well as it's chassis design. These criteria are important for the robot to perform well during the battle.

For my final year project, I have been assigned to develop and fabricate the paintball robot for the next competition, which will be organized in 2014.

1.2 Problem Identification

The main idea of this project is to improve the paintball robot for MIRoC 2014 competition. Based on the analysis on the robot's performance in recent competition, there are a number of key areas that can be further improved for higher performance delivery. Such improvement includes the application of new driving mechanism method of the robot by using Mecanum wheel. Other areas to be improved are as stated below:

a. The mechanism for controlling the robot as current control system cannot be used for Mecanum-wheeled based robot.
b. The robot's chassis design as the current design makes it vulnerable to attacks from the enemy.

1.3 Objectives

The primary objective of this project is to perform improvements to the paintball robot in terms of its electronics, driving mechanism and the chassis design.

In order to achieve this, the project shall meet the following specific objectives:

a. Increase the maneuverability of the robot.
    i. Currently, the robot uses a skid steer driving mechanism which allows front/back and rotational maneuvers.
    ii. The new driving mechanism should have at least three degrees of freedom for increased maneuverability. Proposed mechanism includes using a set of Mecanum wheels to allow the robot to move in front/back, rotational and sideways as well as diagonal maneuvers.
b. Improved electronics for easier control.
    i. The electronics used in the current robot is only applicable for skid steer motion control. For the new driving mechanism, a new control system needs to be developed for easy control

c. Robust chassis design.
    1. The current robot design has an issue in which the robot’s height makes it an easy target for the enemy.
    2. For the new robot, one of the criteria for new chassis design is it must have a low-profile design, where the height is reduced for better performance on the field.

1.4 Scope of study

Before any research is made, the scope of study must be determined so that I can focus on crucial part of this project. The scope of study is listed below:

1.4.1 Understanding on current robot system

In order to improve the robot, understanding of the current system applied to the robot is essential before any improvements can be made. Activities covered in this scope includes understanding the robot’s motion control and the design principle of the chassis

1.4.2 Understanding the new driving mechanism

In this scope of study, understanding on new driving mechanism is important as it will be applied to the new robot. The scope includes on how the wheel design affects its motion and the method used to control the robot when the new driving mechanism is applied.

1.4.3 Design of the electronics control system

By understanding the kinematics of the new driving mechanism, design of suitable control system can be made and applied to the robot. This includes the use of circuit design tool to assist in circuit designing process.

1.4.4 Design of the robot's chassis

By using the information gained from studying the design of earlier robots, a new design is made with consideration on the placement of components and weight distribution on the robot.

1.5 Relevancy of the project

From my point of view, this project is relevant for me to take as it involves many areas of engineering, not just electrical and electronics field of study. As a student majoring in Power Systems, I can focus on the motor selection for the robot's drive wheels. By taking this project, I can also cover more knowledge in other EE fields such as control systems engineering and embedded systems engineering.

Apart from that, the results of this project can be applied for other researches, especially in motion control and robotics.

1.6 Feasibility of the Project within the scope and time frame

The project duration fit just nicely with the duration of the Final Year Project subject, which is approximately 8 months. As this project only focuses on improvements based on current robot, the period is feasible for me to undertake the project. The usage of Gantt Chart give me much better view on what to be done, scope of learning and the time management throughout the project.

CHAPTER 2

LITERATURE REVIEW

This chapter focuses on the literature review that has been made prior to execution of the project. Literature review is an important process as it provides understanding on certain subjects that is needed to proceed on a project. In my project, knowledge on robotics and driving mechanism or locomotion is important as this will affect the result of my project.

2.1 Robot locomotion

In robotics terminology, locomotion can be defined as the movement method of the robot. A mobile robot needs certain locomotion mechanism to move around its environment [1]. There are a number of methods can be applied to enable movements of a robot such as using legs and wheels. For a wheeled robot, there are a number of methods of locomotion such as normal steer locomotion, skid steer locomotion and omni-directional locomotion using non-conventional wheel, notably omni-directional wheel and Mecanum wheel.

2.1.1 Mecanum wheel

Designed in 1975 in Sweden by Bengt Ilon, the Mecanum wheel is a type of non-conventional wheel that has attached rollers around its circumference, aligned 45° to the axle of the wheel. This wheel configuration, as shown in **Figure 1** allows the robot to move in 2-dimensional plane without the need of conventional steering mechanism [2]. On top of that, robots using this wheel configuration are able to strafe sideways and diagonally without changing the wheel direction itself [4]. **Figure 2** shows the allowed movements when these wheels are used:

Figure 1: Mecanum wheel [9]

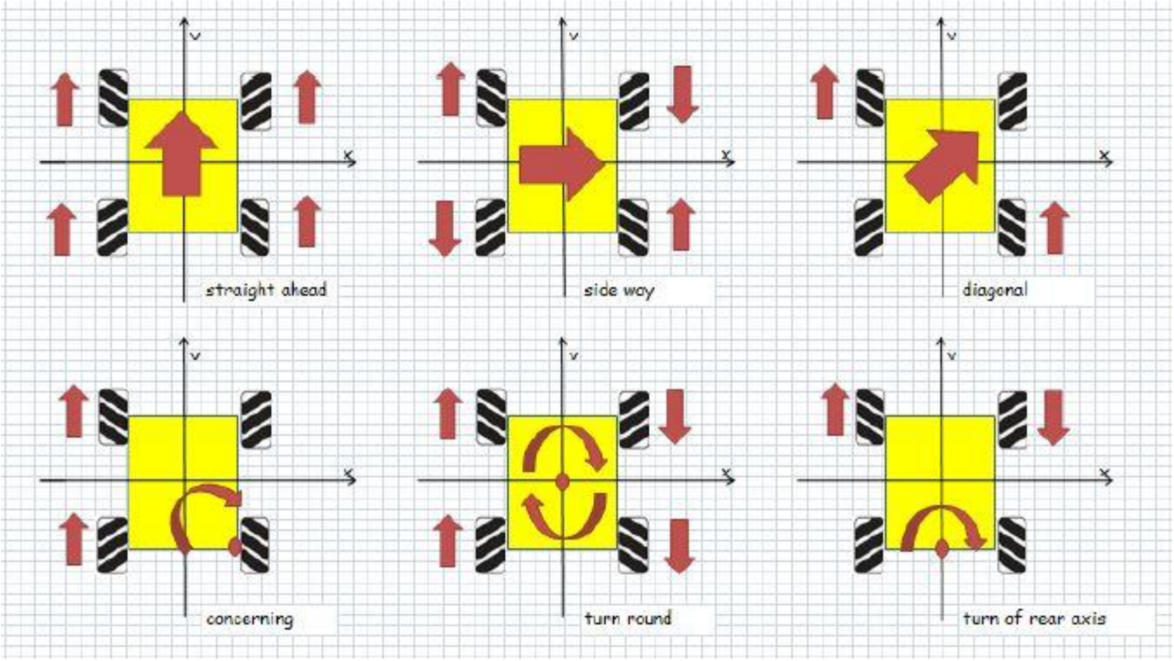


Figure 2: Allowable maneuvers using Mecanum wheel [9]

In order to achieve these movements, the Mecanum wheels are attached to its independent drivetrain i.e. Brushless DC motors. Each motor will drive a wheel and the total force exerted by the wheels will determine the movement of the whole robot. The resultant force vector when each wheel is in motion is shown in **Figure 3**:

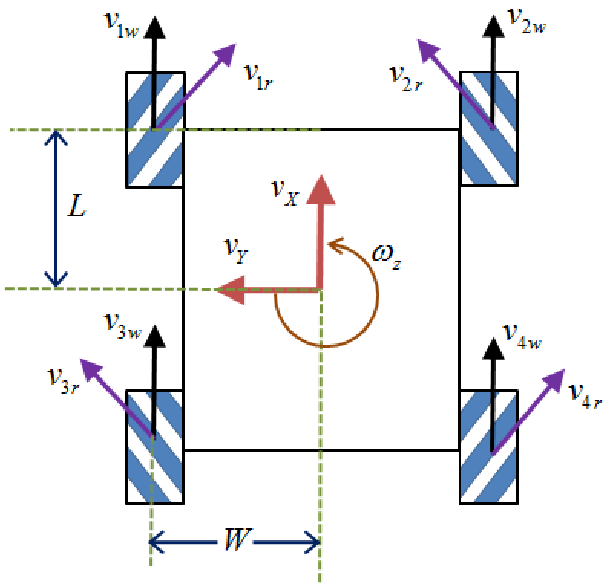


Figure 3: Kinematics diagram of a Mecanum-wheeled robot [3]

The mathematical equation for voltage output of each motor when it is controlled purely by supply voltages for each axis of control are shown as below:

$$V_{m1} = V_x + V_y + V_z \tag{2.1}$$

$$V_{m2} = -V_x + V_y - V_z \tag{2.2}$$

$$V_{m3} = V_x + V_y - V_z \tag{2.3}$$

$$V_{m4} = -V_x + V_y + V_z \tag{2.4}$$

In the above equation, Vx, Vy and Vz are the voltage applied to the motor from the controller, where Vx, is for x-axis control, Vy is for y-axis control and Vz is for rotational control. When the receiver receives the signal, the microcontroller will analyze the signals and assign the values accordingly and then it is manipulated to ensure that the output is not exceeding the maximum limit.

As each wheel is independently-controlled, a specific control system needs to be used as conventional control system implemented in earlier robots cannot be applied in this drive system.

2.2 Mecanum drive control system

As Mecanum wheel locomotion is different to conventional wheel locomotion such as normal steer mechanism which used servos to steer the front wheel and skid steer locomotion using differential method, a new control circuit needs to be applied to control each wheel, allowing it to perform the maneuvers smoothly.

There are several ways to control a Mecanum-wheeled drive system and one of it is by using a microcontroller [2]. In the paper by Cooney (2004), the microcontroller is used to receive, analyze the input and maneuver accordingly. The input of the microcontroller comes from two optical mouse sensors and based from the input analysis, the microcontroller sends out 8 different output signals, which are the Pulse-width modulation signal for motor speed control and the direction of motor rotation signal. As for this project, I will be using a radio control as input to the system instead of pre-program the route into the microprocessor. The microprocessor will mix the radio control receiver’s signals and sends out the outputs to the DC motor driver circuit. Radio control-based input system for Mecanum drive has been studied and applied in several works [5][6]. From the studies, the radio control unit can be interfaced with the microcontroller to control the robot.

2.3 Motor Drive

Another consideration in developing the robot is to select the motor drive for the wheels. For a small robot, DC motor drive is favorable due to small size compared to AC motors. For DC motor, it can be separated into 2 types, which are brushed, and brushless.

2.3.1 Brushless DC Motor

A Brushless DC (BLDC) motor is a motor which has a reversed construction in reference to conventional brushed DC motor. Instead of having the coils on the stator, the BLDC motor has a coil winding at its stator side, and permanent magnets on the rotor side [10]. This construction eliminates the use of brushes to transfer current to the coils for magnetic field generation.

There are many advantages of using a BLDC motor instead a conventional DC motor. The fast dynamic response to reference rotor speed due to low inertia is one of the reasons why BLDC motor is a better choice [7]. The same paper also provides information that BLDC motor is also a better choice due to lower maintenance cost, as the use of brushes has been eliminated. In addition, high precision of BLDC motor makes it more efficient for application where motor speed is important [10]. This precision can be achieved by Hall sensors insude the motor to provide the rotor speed at any time[11]. **Figure 4** shows the photo a BLDC motor and **Figure 5** shows the diagram of a 2-phase BLDC motor:

Figure 4: Inside a BLDC motor in computer cooling fan [10]

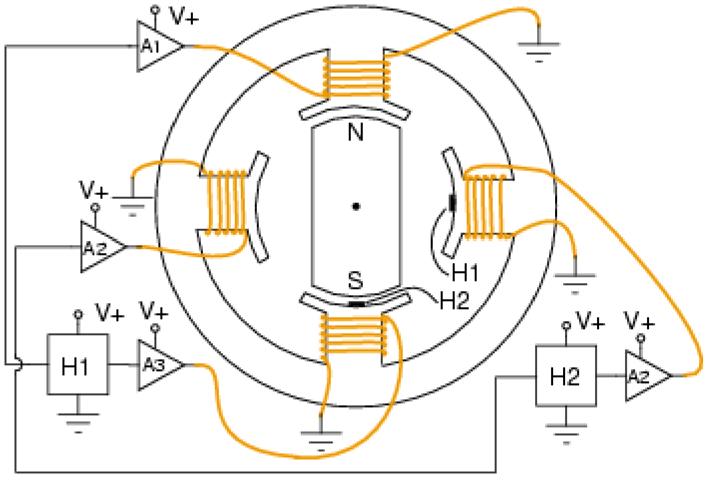


Figure 5: Construction of 2-phase BLDC motor[11]

CHAPTER 3

METHODOLOGY

In this chapter, I will provide the explanation regarding the methods used in executing this project, the time frame of the project, and the software used in this project. Subsection 3.1 explains on the methodology and project activities throughout this project, subsection 3.2 explains the key milestones and Gantt chart of the project and subsection 3.3 provides information on the software used in this project.

3.1 Methodology and Project Activities

In order to complete the project within the time frame, I have divided the task into four distinct phases as below:

Phase 1: Literature review and research work
Phase 2: Design & fabrication of electrical systems
Phase 3: Design & fabrication of the robot’s chassis & mechanical system
Phase 4: Full assembly, testing and improvement

In Phase 1, I start off the project by first assessing the performance of current paintball robot. From my assessment, there are certain points where I will be able to improve which is the robot’s locomotion, control systems (electronics), and chassis design. Based on the assessment, I will proceed with the preliminary research, which needs me to do literature review on the key areas. By doing so, I am able to further understand the concepts and applications that will be developed in the robot later on.

In Phase 2, I will proceed with the conceptual design of the robot. In this phase, I will be focusing on designing the new control system to be fitted into the robot as new locomotion system will be implemented in this robot which uses a set of Mecanum wheel. After the conceptual circuit design is complete, I will start with the circuit fabrication and assembly, and put the system into the test unit. The result of this test will be assessed and modifications will be made if necessary.

After all the electronics design and fabrication phase has been completed, I will proceed to Phase 3, which is design and fabrication of the robot's chassis and mechanical systems. For this phase, I will design the robot's chassis using computer-aided design software, or CAD. Once approved, I will start the fabrication process of the chassis. After the fabrication is complete, I will proceed to Phase 4, which is full assembly of the robot.

In Phase 4, the control unit and drivetrain will be assembled into the fabricated chassis. Once assembled, the robot will run through a series of tests to ensure that all systems in the robot functions as planned. The documentation on this project will also be made during this phase. **Figure 6** shows the flow diagram of the project:

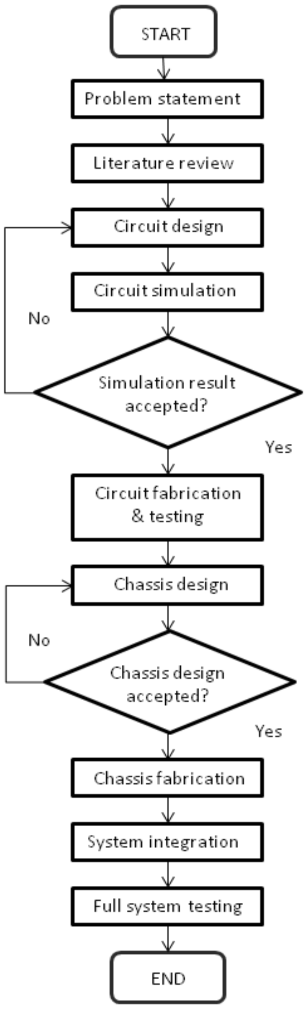


Figure 6: Flowchart of the project

3.2 Key milestones and Gantt chart

Table 1 and **Table 2** shows the deliverables and work period for my project work during the project period of 28 weeks:

TABLE 1: Key Milestones - FYP 1

Event or Deliverable	Work period
Project title selection	Week 1-2
Project execution: Phase 1 - Research work & Literature review	Week 3-6
Project extended proposal submission	Week 6
Project execution: Phase 2 - Design of control system	Week 6-8
Preparation for Proposal Defense	Week 7-8
Proposal Defense presentation	Week 8
Project execution: Phase 2 - Fabrication & testing of control system	Week 10-12
Project Interim Report submission (Draft)	Week 13
Project Interim Report submission (Final)	Week 14

TABLE 2: Key Milestones - FYP 2

Event or Deliverable	Target
Project execution: Phase 2 - Fabrication & testing of control system - continuation	Week 15-18
Project execution: Phase 3 - Design of robot chassis	Week 19-20
Project execution: Phase 3 - Fabrication of chassis	Week 21-22
Project Progress Report submission	Week 21
Project execution: Phase 3 & 4 - Fabrication and full assembly of system	Week 22-23
Preparation for Electrex	Week 23-24
Project execution: Phase 4 - Improvement on system	Week 22-28
Project Final Report submission (Draft)	Week 27
Project Final Report submission (Final)	Week 28
Project viva	Week 29

TABLE 3: Gantt chart - FYP 1

Activity/Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Project title selection	🟨	🟨												
Project execution: Phase 1 - Research work & Literature review			🟨	🟨	🟨	🟨								
Project extended proposal submission						🟨								
Project execution: Phase 2 - Design of control system						🟨	🟨	🟨						
Preparation for Proposal Defense							🟨	🟨						
Proposal Defense presentation								🟨	🟨					
Project Execution: Phase 2 - Fabrication & testing of control system									🟨	🟨	🟨			
Project Interim Report submission (Draft)										🟨	🟨	🟨		
Project Interim Report submission (Final)													🟨	🟨

TABLE 4: Gantt chart - FYP

Activity/Week	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**
Project execution: Phase 2 - Fabrication & testing of control system - continuation	🟨	🟨	🟨	🟨											
Project execution: Phase 3 - Design of robot chassis					🟨	🟨									
Project execution: Phase 3 - Fabrication of chassis							🟨	🟨							
Project Progress Report submission							🟨								
Project execution: Phase 3 & 4 - Fabrication and full assembly of system								🟨	🟨						
Preparation for Electrex									🟨	🟨					
Project execution: Phase 4 - Improvement on system								🟨	🟨	🟨	🟨	🟨	🟨	🟨	
Project Final Report submission (Draft)													🟨		
Project Final Report submission (Final)														🟨	
Project viva															🟨

3.3 Tools, Hardware and Software

Table 5 below shows the software used during the course of this project

TABLE 5: List of Software Used

Software	Description
Microsoft Office 2007	Documentation and project works
NI Multisim 11	Circuit design & simulation software
Eagle 6.4	PCB design suite
Google SketchUp	3D CAD software for chassis design

CHAPTER 4

RESULTS AND DISCUSSION

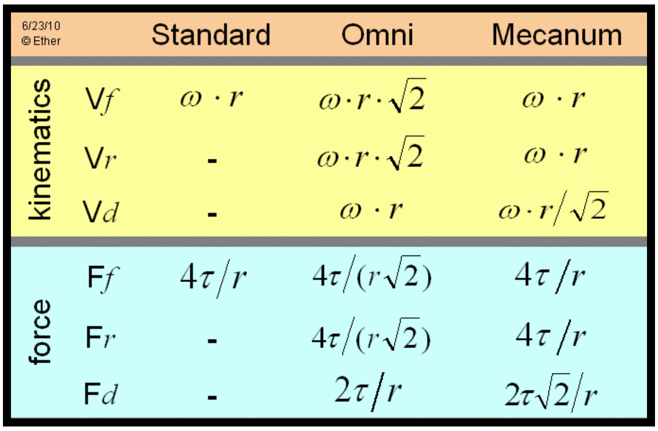
In this chapter, I will explain on the results of this project. Subsection 4.1 covers the locomotion of the robot and its justification subsection 4.2 explains about motion control method of the robot, subchapter 4.3 covers the design and fabrication of the mixer circuit. Subchapter 4.4 will provide information on the chassis fabrication for the robot and subchapter 4.5 covers the robot assembly and testing result.

4.1 Locomotion of the robot

This section covers on the locomotion methods of the robot, where the selection of the locomotion for the robot is made. Based on the study on many types of locomotion available, a wheeled robot is a better choice as the robot needs to move at high speed. From there, various wheel types are studied, such as conventional, omni-directional and Mecanum wheel. In the selection of wheel type to be applied, it must be able to pass on the criteria set, which are:

1. The wheel used allows the robot to move in any direction
2. The wheel can be used on rough surfaces
3. Easy assembly to the chassis

From the criteria listed, Mecanum wheel was selected to be applied to the robot for its ability to allow sideway and diagonal motion, which cannot be achieved by using conventional wheel. Mecanum wheel is also a choice due to its high torque available for same speed in comparison to omni-directional wheel, as indicated in **Figure 7**.



6/23/10 © Ether		Standard	Omni	Mecanum
kinematics	Vf	$\omega \cdot r$	$\omega \cdot r \cdot \sqrt{2}$	$\omega \cdot r$
	Vr	-	$\omega \cdot r \cdot \sqrt{2}$	$\omega \cdot r$
	Vd	-	$\omega \cdot r$	$\omega \cdot r / \sqrt{2}$
force	Ff	$4\tau / r$	$4\tau / (r\sqrt{2})$	$4\tau / r$
	Fr	-	$4\tau / (r\sqrt{2})$	$4\tau / r$
	Fd	-	$2\tau / r$	$2\tau\sqrt{2} / r$

Figure 7: Kinematics and force comparison for conventional, omni and Mecanum wheels[8]

For the same wheel speed, omni-directional wheels can achieve higher speed than Mecanum, but Mecanum wheel has higher driving force than omni wheel, which is better for this robot as it needs to climb ramps. With higher force exerted, climbling up the ramp will be easier.

In addition, Mecanum wheel is also easier to assemble as it can be assembled the same way as normal wheel unlike omni-directional wheel in which it needs to be assembled at 45° to the base, as indicated in **Figure 8.**

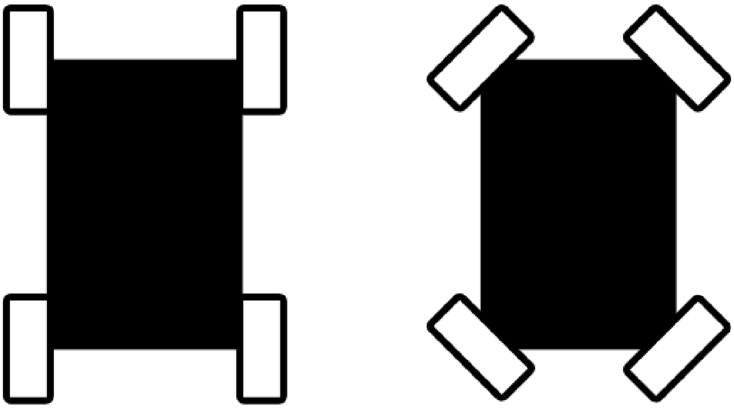


Figure 8: Wheel mounting of Mecanum wheel (left) and Omni wheel (right)

Another reason for the application of Mecanum wheel locomotion in the robot is because it allows the robot to transverse in both smooth floors and slightly rough surfaces such are tarmac. This is an advantage as omni-directional wheels only can travel on smooth surfaces as rough surfaces can damage the wheel rollers.

4.2 Robot motion control method

This section covers on the method of controlling the robot’s motion. By studying many wireless methods to control a robot such as Wi-Fi, it was decided to use a 2.4GHz Direct Sequence Spread Spectrum (DSSS) radio control system commonly found in radio control hobby kits. The reason that this system is chosen is due its robustness and simplicity, as this system has low narrowband interference than conventional radio control system and easier for control as the operator needs to have mobility, in which it cannot be achieved if Wi-Fi connection from a laptop is used. In addition, applying this control method makes replication of the system to be easier as there are no programming involved.

For the control circuit, two units of skid steer decoders in which one set decodes the robot’s y-axis and z-axis rotation movement and the second set decodes x-axis movement. The decoder’s documents can be referred in Appendix A. Both decoders are connected to a mixer, which is self-designed using three logic gates (AND, OR and X-OR gate) to mix both decoders’ motor direction and motor state logic signal. The mixed signals are then sent to the motor drivers, which controls the brushless motor driving the wheel. The specification of the motor and drivers can be viewed in Appendix B. **Figure 9** shows the block diagram of the robot’s motion control.

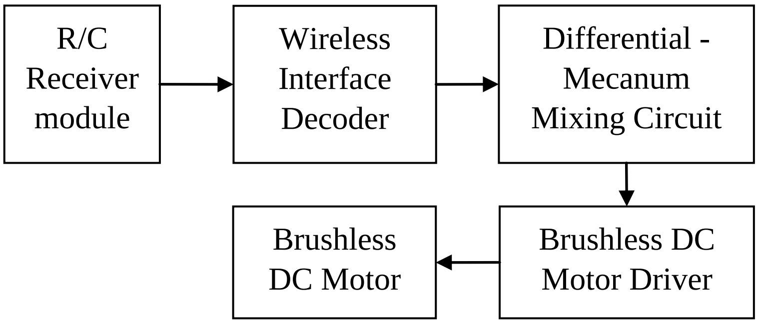


Figure 9: Block diagram for motion control

By adding the mixer, the operator can use only one control stick for rotation, and one control stick for lateral movement, although two-stick operation is needed for sideways movement. This is an advantage as the operator can use one thumb for motion control, and other thumb for shooting, instead of using two thumbs for motion, which is more complicated.

4.3 Mixer design

This section cover the details of the mixer designed to be used to mix the decoder’s signals so it can drive the Mecanum wheels. The skid steer-Mecanum drive system mixer is designed to enable the robot to use Mecanum wheels, when only the skid-steers decoders are available. The decision to design is made in such a way is to make replication easier for the other robot designers later when they wanted to apply the system. The first phase of the circuit design is mapping of the output of both skid steer decoders and paired it with the necessary input for each motor driver. **Table 6** shows the output state for the decoders and the input needed for the Mecanum drive to work:

TABLE 6: Logic state table for decoder and driver

Direction	**Decoder output** **(Motor direction)** **0 = Clockwise** **1 = Counter Clockwise**				**Driver input** **(Motor direction)** **0 = Clockwise** **1 = Counter Clockwise**				**Driver input** **(Motor state)** **0 = Motor run** **1 = Motor stop**			
	1A	1B	2A	2B	M1	M2	M3	M4	M1	M2	M3	M4
FW	0	0	1	0	1	0	0	1	0	0	0	0
RW	0	0	0	1	0	1	1	0	0	0	0	0
ROT-L	0	0	0	0	0	0	0	0	0	0	0	0
ROT-R	0	0	1	1	1	1	1	1	0	0	0	0
STR-L	0	1	0	0	0	0	1	1	0	0	0	0
STR-R	1	0	0	0	1	1	0	0	0	0	0	0
DIA-FWL	0	1	1	0	1	0	1	1	1	0	1	0
DIA-FWR	1	0	1	0	1	1	0	1	0	1	0	1
DIA-RWL	0	1	0	1	0	1	1	1	0	1	0	1
DIA-RWR	1	0	0	1	1	1	1	0	1	0	1	0

In reference to the table above, Decoder 1 controls the x-axis direction of the robot and Decoder 2 controls the y-axis and rotation of the robot. Based on this information gathered from the datasheets and testing the decoders and drivers, I applied Karnaugh map as a process to design the circuit. The designed mixer circuit is shown in **Figure 10**.

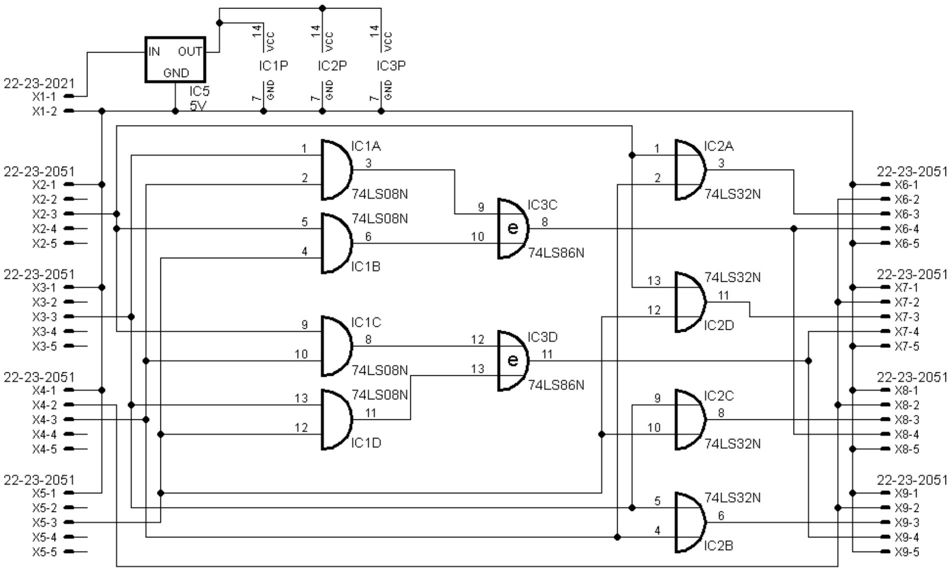


Figure 10: Mixer schematic design

The circuit was designed by applying Karnaugh map method in determining the gates for each output. After the K-map is complete, the needed gate for direction logic is OR gate and for motor state, the needed gate is AND and XOR gate. The K-maps and Boolean equations of directional and motor state of the motors can be referred in Appendix C.

After the design and simulation of the circuit was done, the circuit was fabricated on a breadboard for preliminary testing. From the test, the circuit works as designed and the design was transferred it to a Veroboard. **Figure 11** shows the fabricated circuit on a Veroboard.

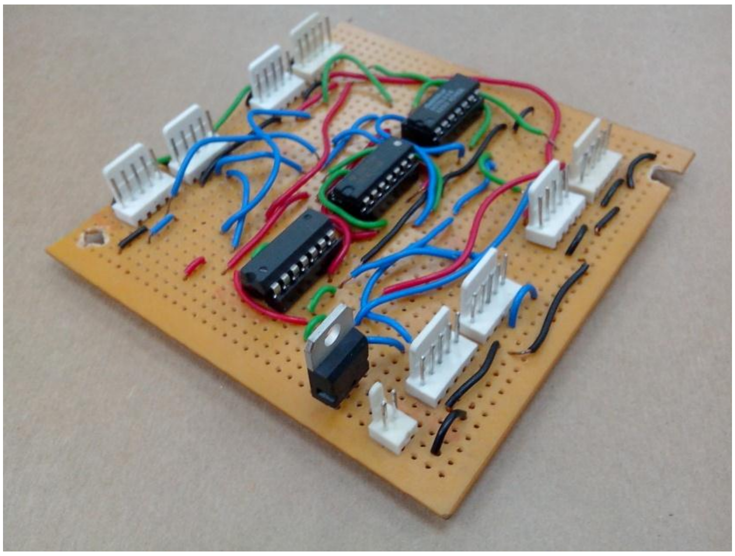


Figure 11: Fabricated mixer circuit

After the circuit fabrication process, characterization on the finished board was made. It is important to characterize the board so that it is compatible with other boards to avoid damages to the system as an incompatible system may cause damage to the boards, affecting its performance. **Table 7** shows the electrical specification of the mixer board.

TABLE 7: Mixer board system characteristics

Item	Value
Operating voltage	5.0 - 12.0 V
Number of I/O ports	8 (4 Input/4 output)
Signal type per port	2 digital signal pin 1 PWM/analog signal per connection
Input voltage	0 - 5.0 V
Output voltage (digital)	5.0 V
Output voltage (PWM)	0 - 4.95 V

4.4 Robot chassis design

After reviewing earlier robot design used and designs from other robots with same function, a design was made which tackles one of the project’s objectives; to have a low profile chassis design to reduce chances of being hit. In earlier chassis, the paintball gun is mounted at higher position since the platform is packed with electronics and the pressure canister for the gun, reducing space for gun positioning.

The solution applied to tackle the issue is to make the chassis hollow, so that the paintball gun can be mounted at a lower position. A hollow chassis also helps in weight reduction, which affects the robot’s maneuverability and speed. **Figure 12** and **Figure 13** shows the design of the robot platform without the paintball component and the robot platform with the gun and canister added.

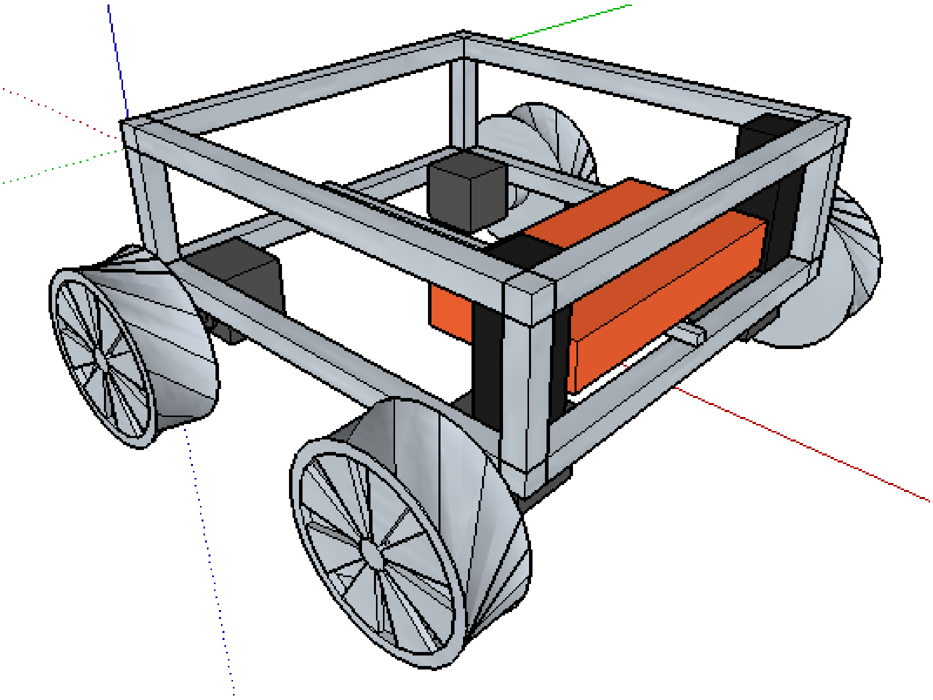


Figure 12: Designed robot platform

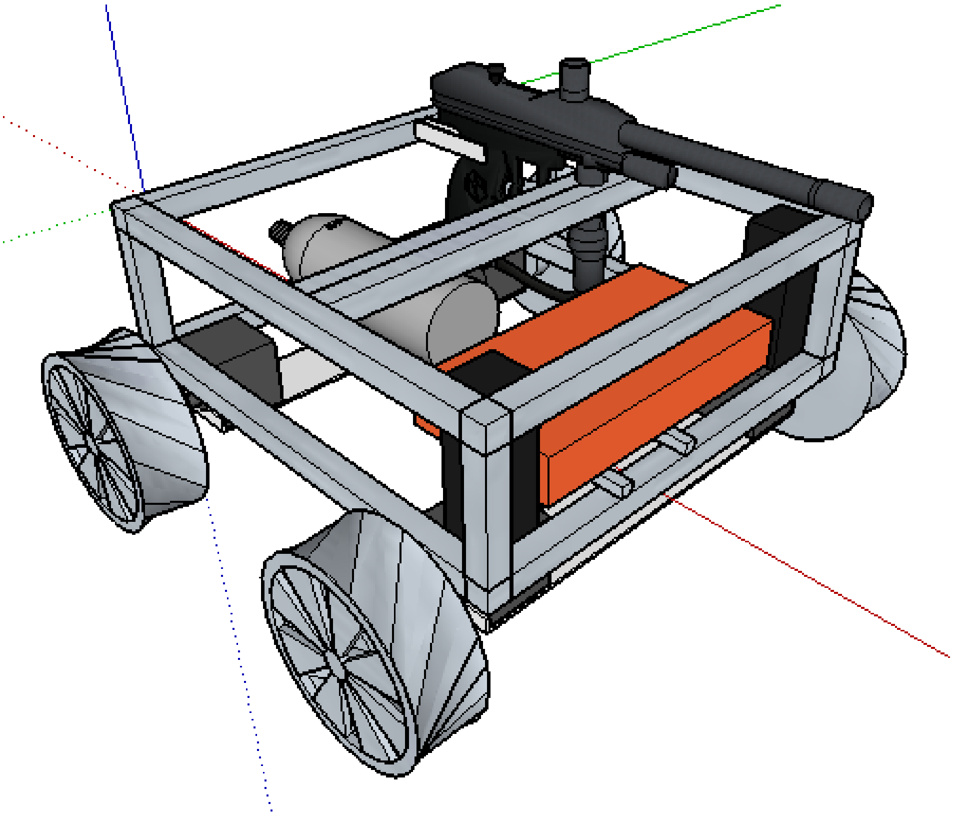


Figure 13: Designed robot platform with gun mounted

After the design is checked and approved, the fabrication process started. The chassis is built using aluminium rod with 2cm height and 2cm width. In assembling the chassis, rivets is used to connect the aluminium rods for added rigidity as there is a possibility that the chassis will fall apart if nuts and bolts are used. **Figure 14, 15 and 16** shows the fabricated chassis for the paintball robot. **Figure 17** shows the covered chassis of the robot. **Table 8** shows the dimensions of the robot chassis.

TABLE 8: Dimensions of the robot

Item	Measurement (cm)
Chassis height	14
Chassis length	41
Chassis width	39
Assembled platform height	20
Assembled platform length	46
Assembled platform width	46

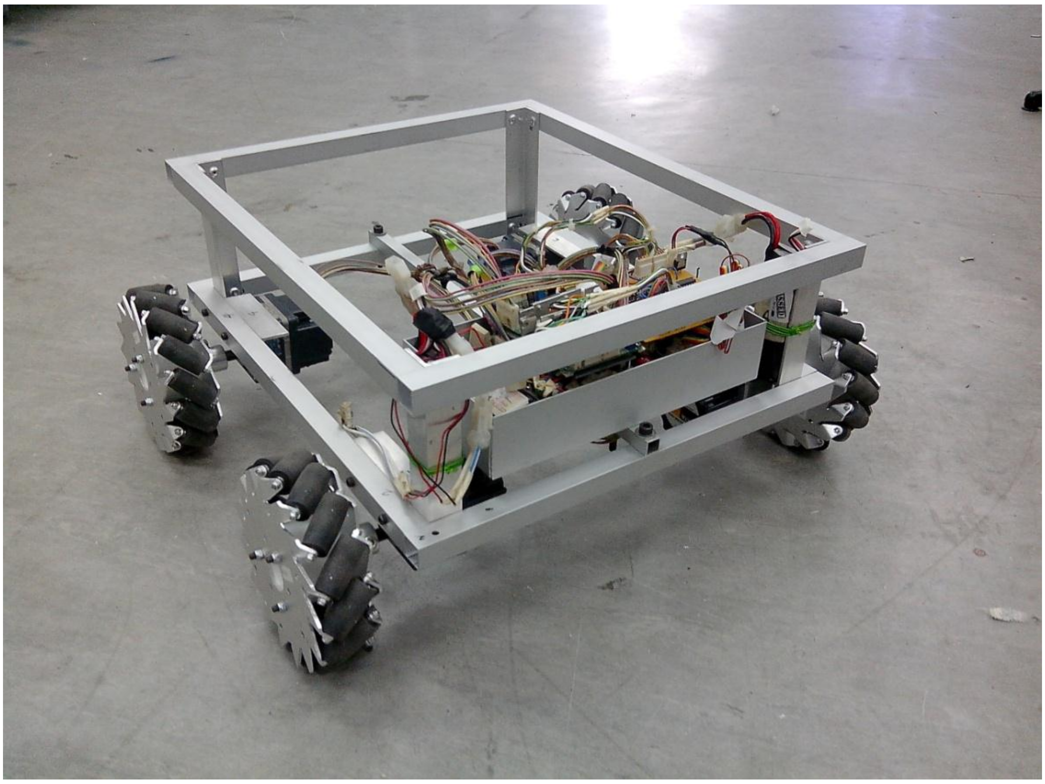


Figure 14: Fabricated chassis - Isometric

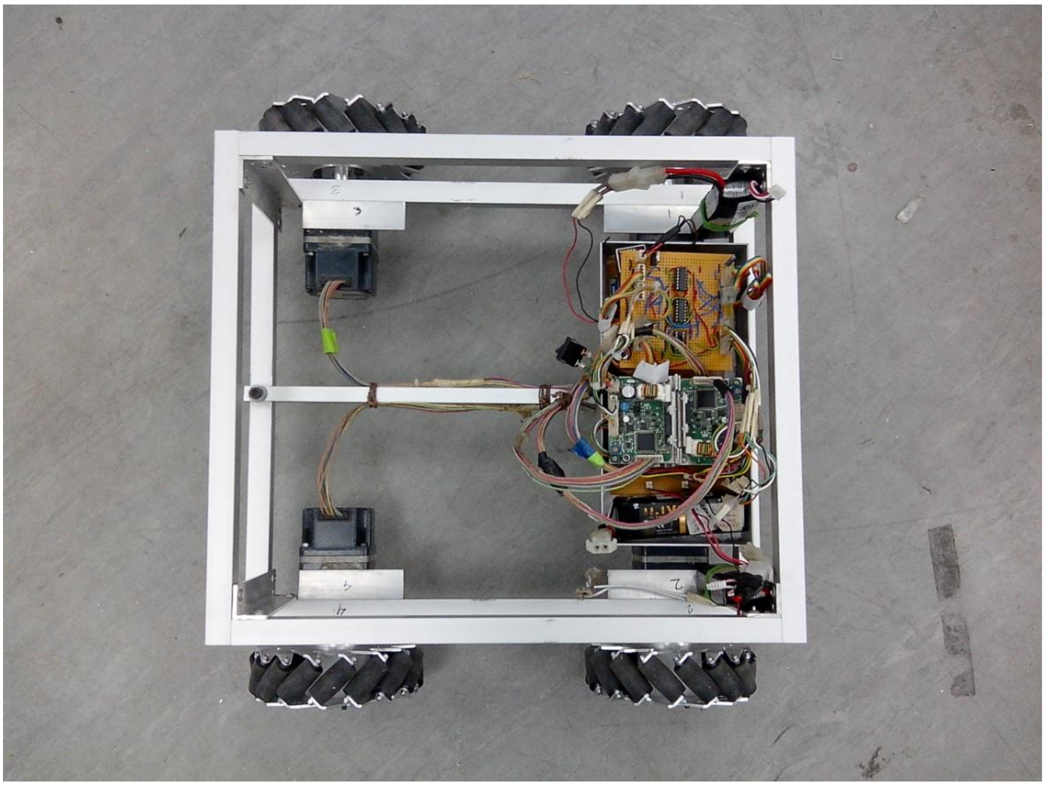


Figure 15: Fabricated chassis - Top

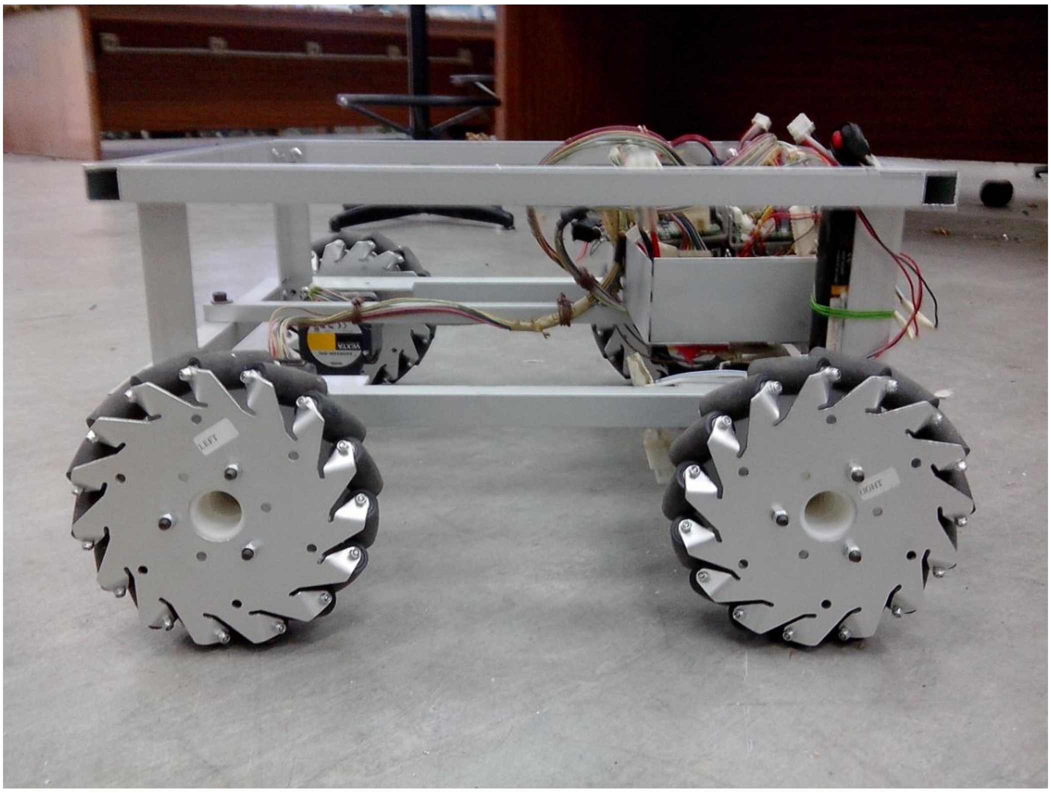


Figure 16: Fabricated circuit - Right

Figure 17: Fabricated circuit - Covered

4.5 Robot assembly and testing

After the circuit and chassis are ready, the components were then assembled and the robot is put for testing. The tests that were run are speed test, range test, duration test and maneuverability test.

For speed test, the robot theoretical maximum speed was calculated as follows:

$$Circumference\ (m) = \pi d$$

$$= \pi \times \frac{152}{1000}\ , d = 152mm$$

$$= 0.4775\ m$$

$$Speed\ (v) = \frac{Distance(m)}{Time(s)}$$

$$Speed\ (v) = 0.4475\ m\ \times \frac{250\ rpm}{60\ s}$$

$$= 1.9897\ m/s$$

In the speed test, the speed recorded is lower than the theoretical speed, which is 1.95 m/s. This is due to the load on wheels and the limit on the decoder which supplies 99% of the maximum voltage (4.95 V supplied).

For range test, we are able to control the robot up to 90 meter from the remote transmitter, which is sufficient. The range is limited by the radio transmitter. If the transmitter is upgraded, the coverage will be wider and the robot can be controlled at longer distance.

In duration test, the robot can operate up to 30 minutes using two 12V Lithium Polymer batteries. For the control circuit, the duration is longer due to lower voltage requirement. The full testing is still being done to get the better result.

For controllability test, the robot moves as it was designed, which are forward/reverse on y-axis, sideways on x-axis, diagonal movement and rotation on z-axis. The available moves of the robot platform are shown in **Figure 18**.

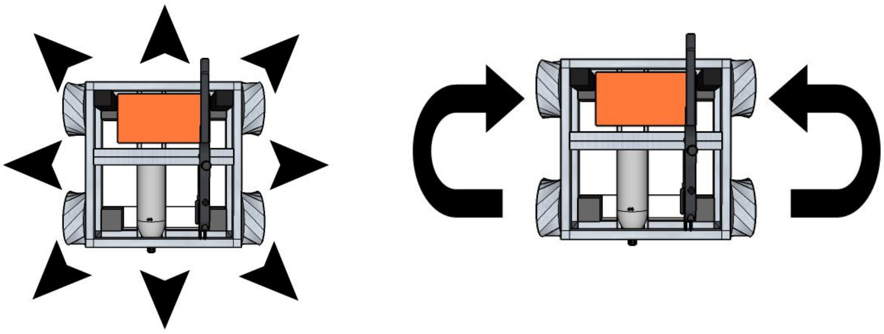


Figure 18: Available movements achieved using deployed system

To control the robot, the operator will use the left stick to control the x-y axis and the right stick to control the rotation. At low and medium speed, the balance is achieved when the robot moves in a straight line but diverts a bit when at high speed. This is due to the unsymmetrical weight distribution on each wheel. This problem has been resolved by adding a bracket at the motors to assist in weight support.

CHAPTER 5

CONCLUSION

5.1 Conclusion

By performing researches and study on earlier design of the paintball robot, I am able to complete the project’s objectives which are to design a paintball robot with a better chassis and have a better steering system to give the robot a better maneuverability than its predecessor. By applying hollow chassis design, we are able to have the gun mounted at lower height, which further reduce the height of the robot, making it less vulnerable to enemy. The use of Mecanum wheel in this robot gives it added advantage as this system allows the robot to move in all directions with no problem, increasing its maneuverability. Simplified control system also assists in which the operator can learn the controls in a short time, rather than using conventional two-stick Mecanum wheel control.

Based on the results, the robots work and performed as designed and with it, we have acquired the technology that gives us an added advantage on the competition later.

Although this project is focused on robotic competition, this technology can be deployed for other used as well, especially in transportation field as it is deemed useful for us.

5.2 Recommendation

There are a few recommendations that can be made to further improve the project:

- A suspension system can be applied so that the robot can move on rough surfaces with minimal damage on the wheel and chassis

- Use of dedicated microprocessor to directly control the motors instead of using decoders and mixers. This will save space for electronics inside the robot.
- Attachment of video camera to assist in robot targeting.

REFERENCES

[1] Böttcher, S. (2006). Principles of robot locomotion. Proc. Human Robot Interaction Seminar SS.

[2] Cooney, J. A., et al. (2004). "Visual dead-reckoning for motion control of a Mecanum-wheeled mobile robot." Mechatronics 14(6): 623-637.

[3] Kim, J., et al. (2011). "Inertial Navigation System for Omni-directional AGV with Mecanum Wheel." MIME 2011: 207-273.

[4] Diegel, O., et al. (2002). Improved mecanum wheel design for omni-directional robots. Proc. 2002 Australasian Conference on Robotics and Automation, Auckland.

[5] Firdaus, M. and A. Rashid (2010). "Design And Development Of Manual Robot Using Mecanum Wheels."

[6] Zul Azri, Z. (2011). "Design And Development Robot Drive System Using Mecanum Wheel."

[7] Neethu, U.; Jisha, V.R., "Speed control of Brushless DC Motor: A comparative study," *Power Electronics, Drives and Energy Systems (PEDES), 2012 IEEE International Conference on* , vol., no., pp.1,5, 16-19 Dec. 2012
doi: 10.1109/PEDES.2012.6484349

[8] Mecanum and Omni Kinematic and Force Analysis and Programming (2010) Retrieved October 12, 2013, from http://www.chiefdelphi.com/media/papers/2390

[9] A set of Mecanum Wheel - 4 pieces (2012), Retrieved July 15, 2013, from http://www.robot-r-us.com/wheel-mecanum/a-set-of-152mm-mecanum-wheels-4-pieces.html

[10] Brain, M. “How Does A Brushless Electric Motor Works?”, Retrieved August 10, 2013 from http://electronics.howstuffworks.com/brushless-motor.htm

[11] Brushless DC Motor (2003), Retrieved August 10, 2013 from http://www.allaboutcircuits.com/vol_2/chpt_13/6.html

APPENDICES

APPENDIX A

DECODER SPECIFICATION SHEET

DHRobotics Wireless Interface Decoder

Specification:

- 7-12 V input voltage
- 4 selectable operation mode (proportional or differential mode)
- Control via conventional 2.4GHz Radio control unit (2 channels)
- Can be used to control 2 motors via 4 output ports
- Can control motors with rating >2A with external driver
- Internal drivers can be used to control motors with rating <2A
- Plug and Play

APPENDIX B

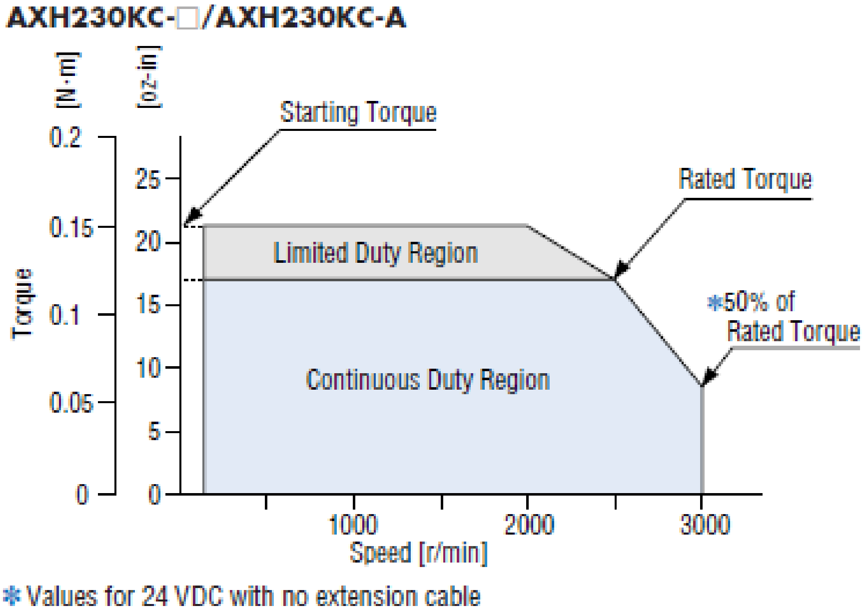
BRUSHLESS MOTOR AND DRIVER SPECIFICATION SHEET

Vexta Brushless DC motor (AHX-230KC-10)

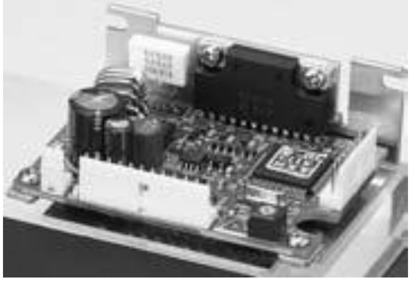
Specifications:

Item	Details
Rated output power	30 W
Input voltage	24 V±10%
Input current (rated/maximum)	2.1 A / 3.5 A
Rated torque	1.1 Nm
Speed range	10 - 250 rpm

Speed-torque characteristics:



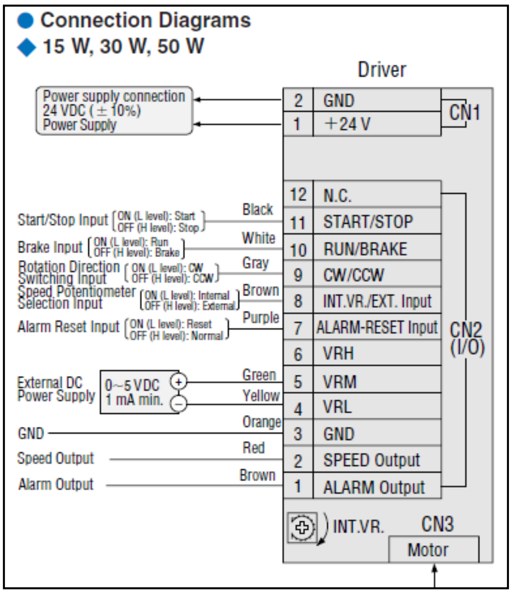
Vexta Brushless DC motor driver (AHXD-30K)

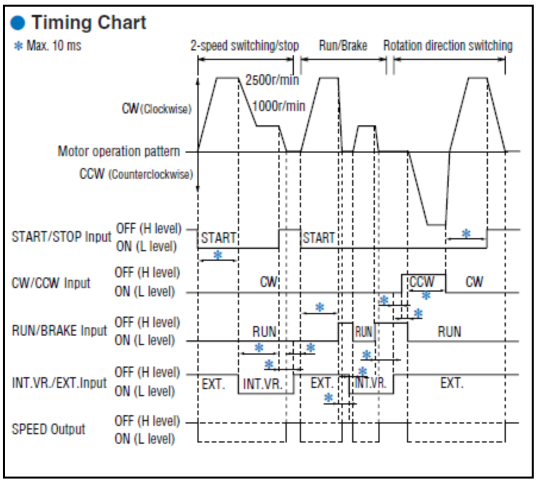


Specifications:

- Input voltage: 24 V±10%
- Input current (logic): 10 mA
- Input current (analog): 1 mA
- Number of pins: 12 pins

Connection diagram:





APPENDIX C

K-MAP AND BOOLEAN EXPRESSSION FOR MIXER CIRCUIT

<table>
<tr><th>K-Map</th><th>Boolean expression</th></tr>
<tr><td>Motor 1 Direction
<table>
<tr><td>C D</td><td rowspan="2">00</td><td rowspan="2">01</td><td rowspan="2">10</td><td rowspan="2">11</td></tr>
<tr><td>A B</td></tr>
<tr><td>00</td><td>0</td><td>0</td><td>1</td><td>1</td></tr>
<tr><td>01</td><td>0</td><td>0</td><td>1</td><td>1</td></tr>
<tr><td>10</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>11</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
</table></td><td>M1 = A + C</td></tr>
<tr><td>Motor 2 Direction
<table>
<tr><td>C D</td><td rowspan="2">00</td><td rowspan="2">01</td><td rowspan="2">10</td><td rowspan="2">11</td></tr>
<tr><td>A B</td></tr>
<tr><td>00</td><td>0</td><td>1</td><td>0</td><td>1</td></tr>
<tr><td>01</td><td>0</td><td>1</td><td>0</td><td>1</td></tr>
<tr><td>10</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>11</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
</table></td><td>M2 = A + D</td></tr>
<tr><td>Motor 3 Direction
<table>
<tr><td>C D</td><td rowspan="2">00</td><td rowspan="2">01</td><td rowspan="2">10</td><td rowspan="2">11</td></tr>
<tr><td>A B</td></tr>
<tr><td>00</td><td>0</td><td>1</td><td>0</td><td>1</td></tr>
<tr><td>01</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>10</td><td>0</td><td>1</td><td>0</td><td>1</td></tr>
<tr><td>11</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
</table></td><td>M3 = B + D</td></tr>
<tr><td>Motor 4 Direction
<table>
<tr><td>C D</td><td rowspan="2">00</td><td rowspan="2">01</td><td rowspan="2">10</td><td rowspan="2">11</td></tr>
<tr><td>A B</td></tr>
<tr><td>00</td><td>0</td><td>0</td><td>1</td><td>1</td></tr>
<tr><td>01</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>10</td><td>0</td><td>0</td><td>1</td><td>1</td></tr>
<tr><td>11</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
</table></td><td>M4 = B + C</td></tr>
</table>

<table>
<tr><th>K-Map</th><th>Boolean expression</th></tr>
<tr><td>Motor 1 and 3 state
<table>
<tr><td>C D</td><td rowspan="2">00</td><td rowspan="2">01</td><td rowspan="2">10</td><td rowspan="2">11</td></tr>
<tr><td>A B</td></tr>
<tr><td>00</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>01</td><td>0</td><td>0</td><td>1</td><td>1</td></tr>
<tr><td>10</td><td>0</td><td>1</td><td>0</td><td>1</td></tr>
<tr><td>11</td><td>X</td><td>1</td><td>1</td><td>X</td></tr>
</table></td><td>$M1 = M3$
$= \bar{A}BC + A\bar{C}D + ABC\bar{D} + A\bar{B}CD$
$= AD(\bar{C} + \bar{B}C) + BC(\bar{A} + A\bar{D})$
$= AD(\bar{C} + \bar{B}) + BC(\bar{A} + \bar{D})$
$= AD(\overline{BC}) + BC(\overline{AD})$
$= AD \oplus BC$</td></tr>
<tr><td>Motor 2 and 4 state
<table>
<tr><td>C D</td><td rowspan="2">00</td><td rowspan="2">01</td><td rowspan="2">10</td><td rowspan="2">11</td></tr>
<tr><td>A B</td></tr>
<tr><td>00</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>01</td><td>0</td><td>1</td><td>0</td><td>1</td></tr>
<tr><td>10</td><td>0</td><td>0</td><td>1</td><td>1</td></tr>
<tr><td>11</td><td>X</td><td>1</td><td>1</td><td>X</td></tr>
</table></td><td>$M2 = M4$
$= AC\bar{D} + B\bar{C}D + \bar{A}BCD + A\bar{B}CD$
$= AC(\bar{D} + \bar{B}D) + BD(\bar{C} + \bar{A}C)$
$= AC(\bar{B} + \bar{D}) + BD(\bar{A} + \bar{C})$
$= AC(\overline{BD}) + BD(\overline{AC})$
$= AC \oplus BD$</td></tr>
</table>