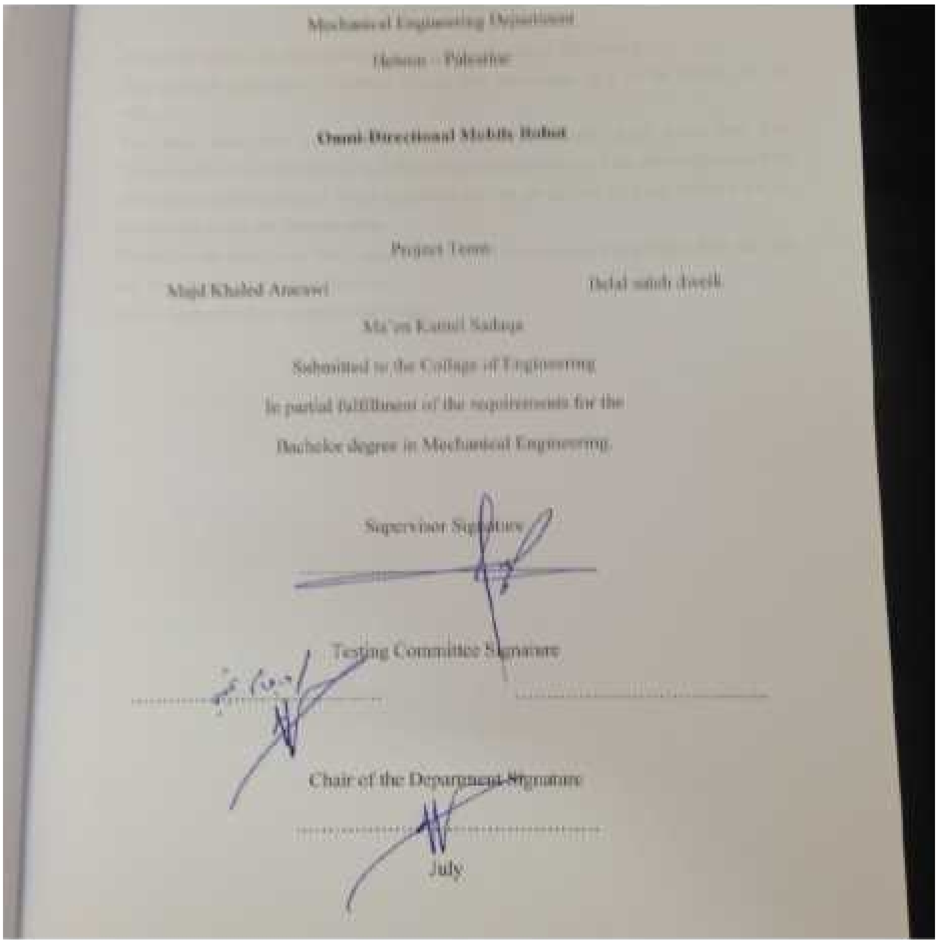
Mechanical Engineering Department

Hebron – Palestine

Omni-Directional Mobile Robot

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Submitted to the College of Engineering

In partial fulfillment of the requirements for the

Bachelor degree in Mechanical Engineering.

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Palestine Polytechnic University

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Palestine Polytechnic University

April 2018

Dedication

First of all, thanks and praise to God for patronizing us work on this project.

This project is dedicated to wonderful parents, who have raised us to be the persons we are today.

You have been with us every step of the way, through good times and bad. Thank you for all unconditional love, guidance, and support that you have always given us, help us to succeed and instilling in us the confidence that we are capable of doing anything we put our mind to. Thank you for everything.

Thanks for our families for their continued support, encouragement and patience from the first step till end, and their best wishes to us.

To our teacher for their advices to our friends.

Abstract

Many factory workers are exposed to injuries due to their work nature, mostly because of currying heavy loads without compliance with safety rules.

This project is a robot consisting of four wheels with a design that allows the robot to move in a diagonal, rotational, and linear ways, and gives it flexibility in mobility within the facility.

The robot is able to lift one hundred and fifty Kg and move with them, and it is controlled using mobile application.

For increased safety, the robot has ultrasonic sensors on the front of it, to ensure thatit will not hit any obstacle in its way.

ملخص

يتعرض العديد من عمال المصانع للإصابات بسبب طبيعة عملهم ، وذلك في الغالب بسبب حمل الأحمال الثقيلة دون الامتثال لقواعد السلامة.

هذاالمشروع هوعبارة عن روبوت يتكون من أربع عجلات بتصميم يسمح لهبالانتقال بطرق قطرية ودائرية وطولية ويمنح المرونة في التنقل داخلالمنشأة.

أيضاً يستطيع هذا الروبوت على رفع مائة وخمسين كغم والتحرك بهم ، ويتم التحكم فيه باستخدام تطبيقللهاتف الذكي، ولزيادة الأمان يوجد لدى الروبوت أجهزة استشعار بالموجات فوق الصوتية في الجزء الأمامي منه ، للتأكد من عدم وصوله إلى أي عقبة في طريقه .

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1.1 Introduction

After the huge industrial evolution, the mobile robots had a huge importance in industrial applications. One of the most important requirements for the mobile robots in industrial field are to get the omni-motion and avoiding obstacles. The main role to achieve these requirementsis the special design of the wheels, which in turn gives the robot the ability to move in several directions and ability to maneuver. There are many kinds of omni-directional mobile robots that have been developed andproduced. There are two typical types of wheels can realize the omni-directional motion, a steerable wheel and an omni-directional wheel. Both of them have been used for mature products, including Adept Seekur and KUKA omni-Rob robots. The steerable wheel has its own rotational mechanism, which can change its steering angle actively, while the omni-directional wheel uses a special wheel structure for flexible movement, examples of which include the Mecanum wheel.

The most important advantages of Mecanum wheel are ideal pushing force, and easy control performances.Mecanum wheels are more appropriate for carrying heavy goods in the industrial environment, this makesMecanum wheel is the good choice for this project.

In this project a design of robot using the Mecanum wheels to get the omni motion and ability to carry heavy load is presented. This robot was designed to carry up to one hundred and fifty kg. The robot was equipped with ultrasonic sensor to keep safedistance between anything and the robot. This robot can be controlled by two modes, remote-control mode (joystick) and line follower mode.

1.2 Recognition of need

Many workers in factories are exposed to many injuries caused by carrying heavy loads.One of solution of this problem is to design a robot that can carry up to one hundredand fifty kg.Because the factories have an inside small space, that make the carrying process harder and the movement process more complex. The robot will be able to move in axial, diagonal and rotational directions. The workerswaste a lot of time and efforts in carrying processes. To save this time and effort a robot with high response will be madewhich willbe controlled by joystick.

1.3Goal and Objectives

The main goal of this project is to design, build and test an omni-directional mobile robot.The objectives of the project search for previous and related works then design a robot, select the appropriate mechanical and electrical component, manufacturing and assembling the robot and programing. Then test the robot and write the project report.

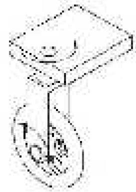
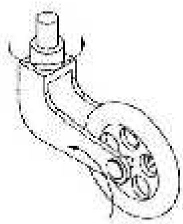
1.4Literature Review

The history of Omni-directional mobile robot that use the Mecanum wheelwhich is inventedin 1973 [1],and used firstlyin1997 [2].Mecanum have ninerollers that are divided on circumference of wheel. Depending on each individual wheel direction and speed, the direction of these rollers makes the resulting force actuate the platform without moving the direction of the wheels [1]. The Omni-directional mobile robot has a special wheel design to give the robot more flexibility in moving than the traditional wheel.Table 1.1shows the advantages and disadvantages for different types of wheels[3], namely:

1- Universal wheel.
2- The Mecanum (Swedish) wheel.
3- The ball wheel mechanism[4].
4- Power steered wheel.
5- Castor wheel.

Table 1.1: Properties of wheel designs.

Wheel type	Advantages	Disadvantages	Wheel shape
Universal wheel (simple)	* low weight, compact design. * simple mechanical design. * commercially	* discontinuous wheel contact or variable drive-radius. * sensitive to floor	

	available	irregularities.	
Mecanum wheel	* compact design. * high load capacity.	* discontinuous wheel contact. * high sensitivity to floor * Irregularities. * complex wheel design.	
Powered steered wheel	* continuous wheel contact. * high load capacity. * robust to floor conditions.	* heavy and bulky design. * high friction and scrubbing while steering. * complex mechanical design.	
Castor wheel	* continuous wheel contact. * high load capacity. * low scrubbing force * during steering. * robust to floor conditions.	* voluminous design. * transmit power and signal across rotational joints. * complex mechanics.	

Depending on Table 1.1the castor wheel and powered steered wheel have a heavy and bulky design, high friction and universal wheel does not have high load capacity. This project requires wheels that can handle heavy loads and has a small design.Mecanum wheel fulfils theserequirements that mean the Mecanum wheel is the “correct” choice for this project.

Other design of Omni-directional mobile robot,is with three wheels Omni-directional mobile robot. The three wheels drive has simple control and steering but limited traction. The four wheels drive has more complex mechanics and control, but higher traction.It was assumed that the front of the robot represents zero degrees direction, and the positive side to its left. The three wheels coupled to the motors are mounted at angle position +60,-60 and +180 degrees respectively as shown in Figure 1.1[5]. Microcontroller in order to give the existing robot any intelligent functionally same form of on board process was essential.

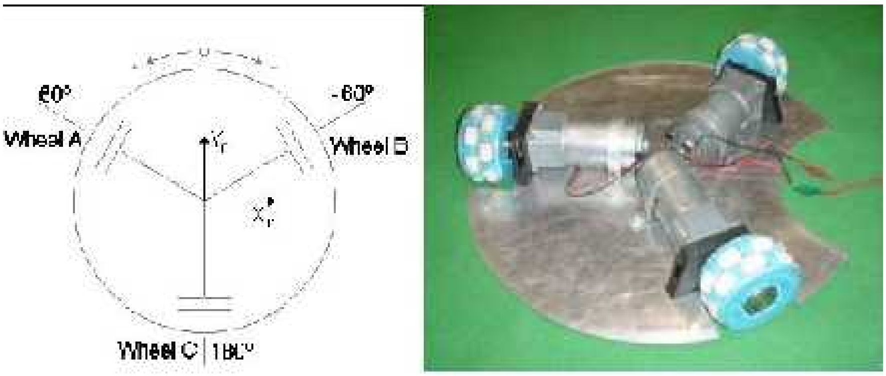


Figure 1.1:omni-directional robot with three wheels.

The Omni-directional wheel technology allows the robot to move in any direction. The wheel consists of two rims and nine free-running rollers, which are mounted at a 45-degree angle. The wheels move independently of each other, which means that the vehicle can move not only forwards and sideways, but also diagonally and in a circle. The entire wheel is driven by an electric motor, and it is available infour different sizes [6].

The gap between the two adjacent rollers causes a periodical vibration in the movingplatform one solution is to use elastic wheel hubs to absorb the vibration [7],and the other solutionadd a suspension system [3]. They are added two pair of Ultrasonic sensor (one pair in the front and one in the back) to scan around of the robot with an angle of 360˚ [3]. They use a PIC16F876 for the robot and to add a line flower application in the robot they are use two OPB704 infrared sensors [3].Kukacompany could produce a robot capable of carrying up to 60,000 kg and mobility in a very small area [8].

The Mecanum wheel has the possibility of slipping.This slipping makes an error in position of robot, to controlled this error there are two methods. One of these methods is using vision system as an absolute position sensor “selected the optical mice as a sensor detecting the robot position”, Butthis method was inaccurate with the surface floor condition.Theother method is to use encoders that will be positioned and connected to the wheel shaft, which we will use[9]. All this paper tocks about sense field do not tock about industry field, the three Omni –direction mobile robot has lower dragging force than the four Omni – directional mobile robot that mean the four wheel is better to the project application.

1.5Literature review summary

The Mecanum wheel was invented in 1973 and the first time used in mobile robot is in 1997. They are many type of special wheel that can use in mobile robot like universal wheel, Mecanum wheel, ball wheel mechanism, castor wheel and powered steered wheel.The Mecanum wheels are the correct choice to give the robot more flexibility in motion, but they have disadvantage, because they have a free roller that make a slipping, and they make a vibration caused by the gap between the rollers.

However, there are two types of omni-directional mobile robot:

1- Four wheels robot.
2- Three wheels robot.

Three wheels robot can be controlled it easily than four wheels robot but it has lower dragging force than the four wheels robot.

Chapter 2
Project Overview

In this chapter,the project will be generally described, and the planned feature is proposed to be in the robot.Then the omni-Directional motion will be describedand show the directional moves of the wheels.

The conceptual design was also discussed in both mechanical and electrical manners. Finally, the controlarchitecture will be described by showing the two control modes of the robot, remote control and line follower modes.

2.1 Robot's features

1. The robot carries up toone hundred and fiftyKg.
2. The robot is equippedwith ultrasonic sensor to keep safety distance between anything and the robot.
3. The robot has a line follower application.
4. The robot is driven by a mobile application.

2.2 Omni-Directional motion

The special design of the Mecanum wheel helps the robot to move in any direction. Figure 2.1[4] shows the Omni motion for the robot, when the four wheels driven with the same speed and to the same direction the robot moves forward and backward and depends on the direction of rotation as shown.If the robot moves to the right or to the left Wheels,1and 4 will rotate to the same direction and Wheels2 and 3 will rotate to the opposite direction, but all wheel have the same speed. To do the forward right or backward motion Wheel, 2 and 3 have the same direction and speed, but wheels,1 and 4 are stopped. The forward left and the back left have the same condition but Wheels1 and 4 are driven and Wheels2 and 3 will stopped. To rotate the robot to the right or to the left the diagonal wheels will driven to the same direction and speed.

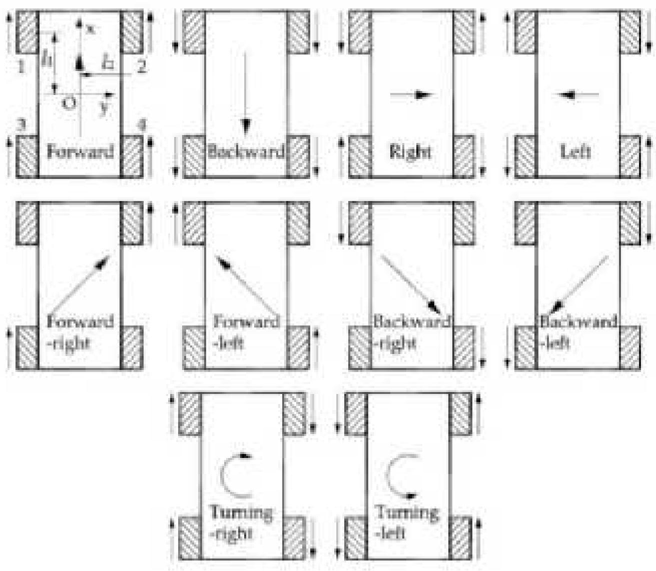


Figure 2.1: Omni-directional motion.

2.3 Conceptual design

The Omni–directional mobile robot is a very important invention in the field of robotics,the robot has a simple mechanical design, and it has a complex electrical design.

Mechanical design:

In mechanical design they are two important thingsthat must be taken into account, the stiffness of material that was used into the robot and the weight of the robot. They, the material that was used in the robot must have a good stiffness and low weight. The aluminum alloy and some type of plastic can be used to achieve properties.

The mechanical design of the robot consists of three parts:

1- Mecanum wheel.
2- Plates (base plate, fixed plate, moving plate).
3- Carrying mechanism (power screw).

The robot uses the Mecanum wheels to get more flexibility in movement,Kuka company [6] makes some analysis explain the rated payload of the robot compared with the diameter of the Mecanum wheel as shown inTable 2.1[6].

The carrying mechanism consist of moving plate, power screw, main gear thatrotates freely and the gear that connected to motor.Figure 2.2show the top view of mechanical design.

Table 2.1: Rated payload of the robot compared with the diameter of the Mecanum wheel.

	250-wheel	310-wheel	375-wheel	575-wheel
Diameter	250 mm	310 mm	375 mm	575 mm
Number of rollers	9	9	8	9
Rated payload	150 Kg	750 Kg	1500 Kg	3000 Kg

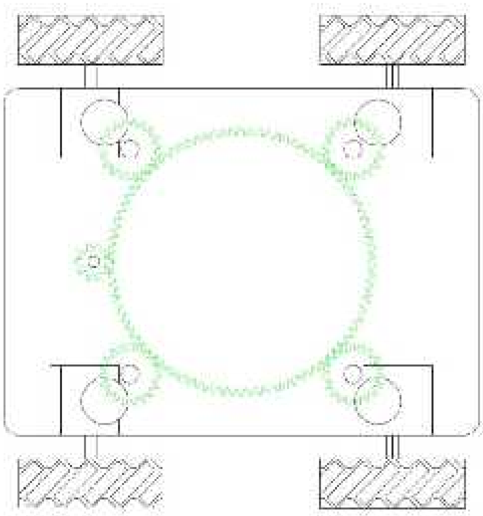


Figure 2.2:Mechanical design.

Electrical design:

This robotuses five motors (24V DC 420 Watt), four of them are connected to the wheels (one motor for each wheel) that can get the omni motion for the robot, and the fifth motor is used in carrying mechanism. This robot uses two ArduinoMega to control all function in the robot and get speed control for the motors. When the robot at the line follower it need the sensor that can detect the line, the color sensor can achieve these Requirements. To maintain a safe distance between the robot and other thing we use ultrasonic sensor.

The power unit in this robot is two-12V batteries that connected together in series form to get 24V. Each motor has one encoder connected with motor shaft, that use to get speed control for each motor.

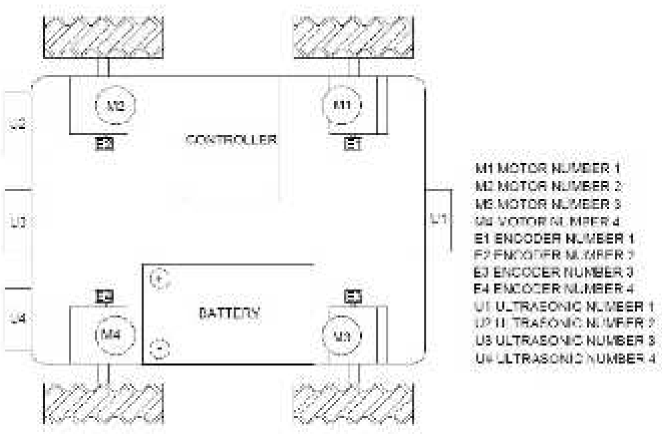


Figure 2.3:Electrical design.

2.4 Control Architecture

The aim of this project is to produce a robot (platform) has a simple controllerand the any end user can controlled it easily, the robot can be controlled with two modes, line follower mode and remote-control modeFigure 2.4 these modes give to the robotmore features.

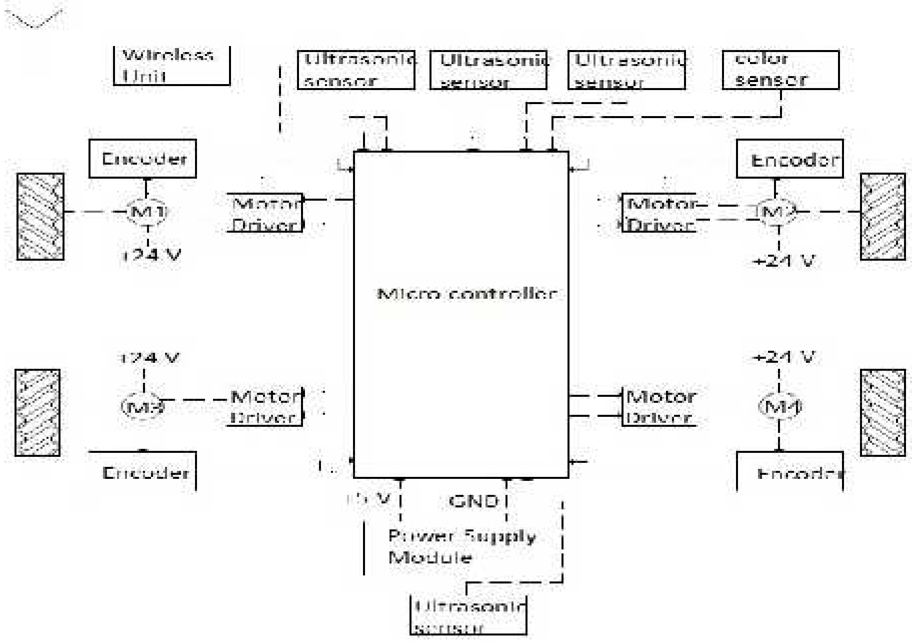


Figure 2.4: controller circuit

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The omni-directional motion needs to control the speed and rotation direction for wheel. That means it will need to connect the encoders to the wheels.It works as feedback sensor.Encoders give the microcontroller the speed and the position for wheels, the microcontroller calculate if it need to correct speed or direction, then sent the command to the motor driverFigure 2.5.

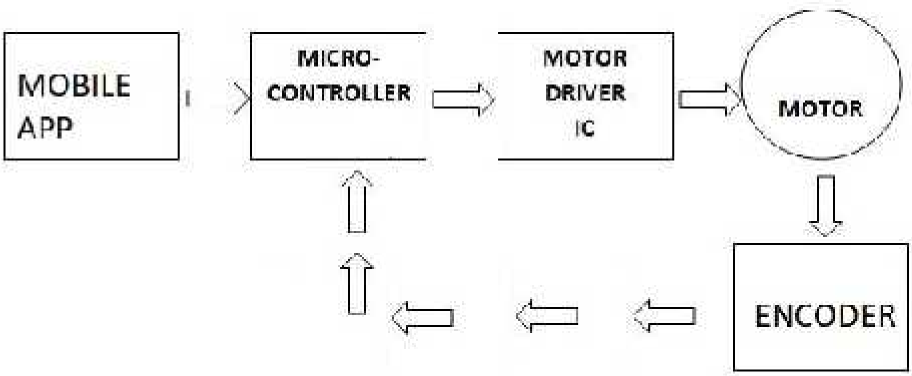

Figure 2.5: Block diagram for controller.

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2.4.1 Remote control mode

In remote control mode, was controlled the movement of the robot used joystick to send the command and wireless unit to receive the command then the micro-controller, so the microcontroller sent the command to the motor driver to set the speed and direction to the motor Figure 2.4.

2.4.2 Line follower mode

The other control mode in this robot is line follower, is to follow the physical line using color sensor, so the color sensor detected the line colors and send the command to the microcontroller then set the correct speed and direction to the motor by command received from microcontroller to the motor driver Figure 2.4.

Chapter 3

Mechanical prototyping

This chapter will describe the mechanical design and electrical design.

3.1 Mechanical Design.

The first step in mechanical design is to know the whole operation of the system and to know how the robot is bind as shown inFigure 3.1.

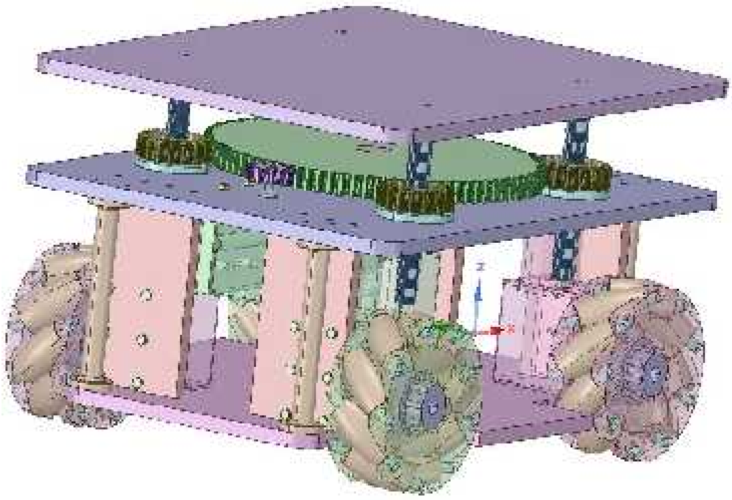


Figure 3.1: final robot's shape.

In the next sections the parts of the robot will be describe in details.

3.1.1 Introduction

In this section, we calculate the mechanical force, selection the material is that used. When talking about mechanical part must be taken into account the weight of robot that not beheavy to get low power to drive it, and stiffness of robot make it possible to carry onehundred and fifty kg.

This robot is divided three parts, which are connected to each other to cover all stages needed, these parts are:

1. Mecanum wheel.
2. Robot's plates.
3. Carrying mechanism (gear, screw).

Since the mechanical component of robot connecttogether produce Omni directional mobile robot determine the motion (axial, diagonal, rotation).

3.1.2 Mecanum wheel

Mecanum wheel show in Figure 3.2contains from four parts:

1. Left and right flange.
2. Wheel holder.
3. Rollers.
4. Screw use fixed flange with wheel holder.

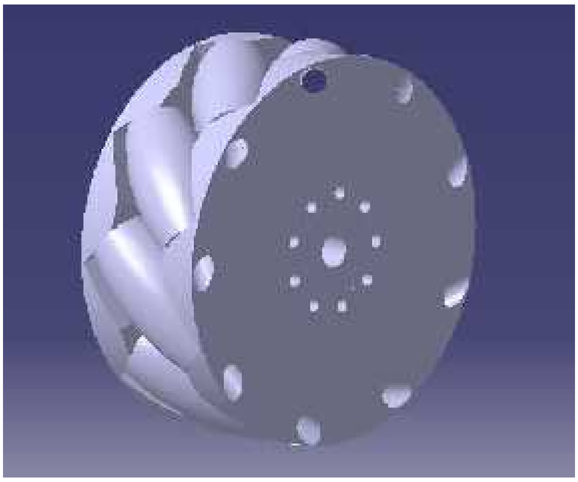


Figure 3.2: Final view of wheel.

Left and right flanges

The mission of this flange is to carry the rollers and it is a part form surface that connected to the ground. The outer Demeter of flange is 236 mm, and mill nine seats have Angele 45 degree can manufacturing by CNC milling machine as shown in Figure 3.3 Most design by using important equations [3].In order to get a circular silhouette for the wheel, a minimum number of rollers should be computed. According to Figure 3.4, if the roller length is chosen, L_r, we get the number of rollers, n.

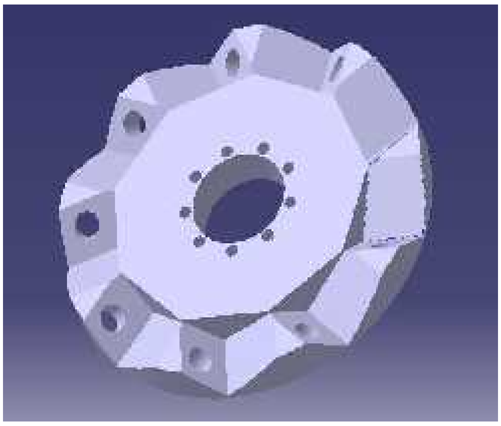


Figure 3.3: wheel flange.

$$n = \frac{2\pi}{\varphi} \qquad (1)$$

$$L\omega = Lr\cos 45° = 2R\frac{\sin\frac{\pi}{n}}{\tan 45°} \qquad (2)$$

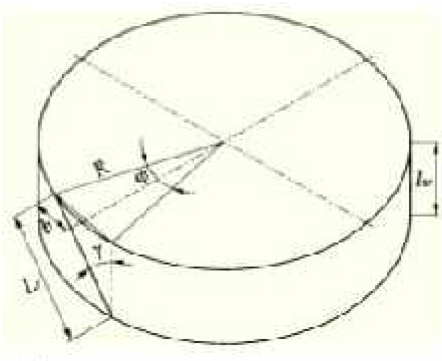


Figure 3.4: wheel parameter.

Wheel holder

Wheel holder shown in Figure 3.5, use to connect two flanges and fixed it in gear box shaft, the marital will be used is an aluminum alloy because aluminum is light than steel.

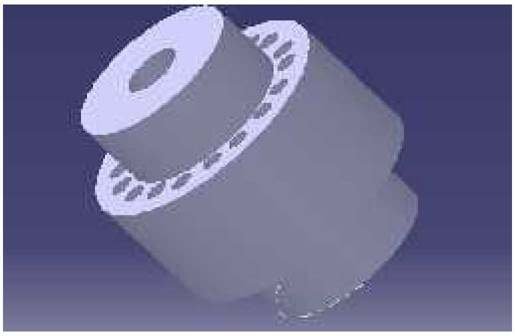


Figure 3.5: wheel holder.

Rollers

This robot will be use nine rollers per wheel see inFigure 3.6, these rollers will be made from plastic using CNC, the shape of rollers can be found form equation below.

$$x^2 + y^2 - R^2 = 0 \quad (3)$$

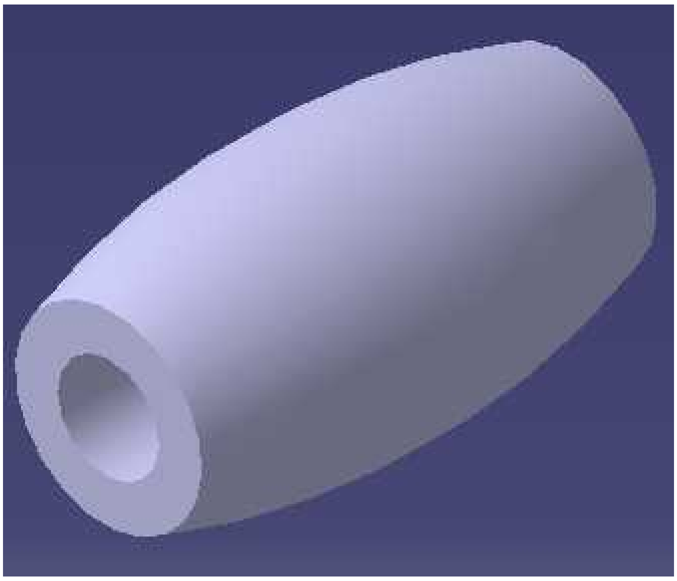


Figure 3.6: wheel's rollers.

Screw use to fixed flange with wheel holder

This screw see in Figure 3.7 build form chrome marital because it has a smooth surface make the roller rotate with slapping (with a little of friction), this shaft has two holes threaded in both side of the shaft use to fix the shaft between two flanges.

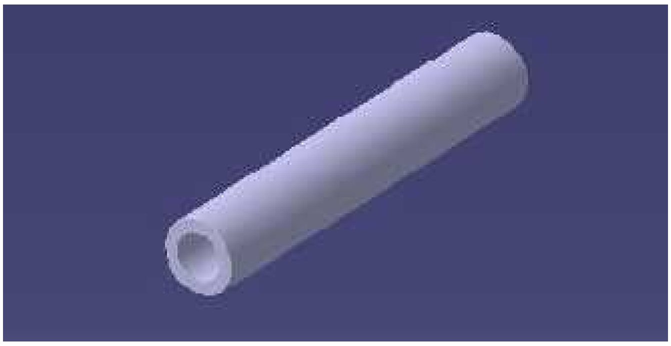


Figure 3.7: screw used to fix the flange with holder.

3.1.3 Robot's plates

The body of this robot have three plates connected together by four iron tube, these plates have bearing holders, this section will be show the dimensions and the material that will be used.

Base

The base of robot see in Figure 3.8 it is the main component that use to compact the other components to gather, the dimension of this plate is600mm × 820mm and the thickness is 20mm, it is made formAluminum alloyto get lose weight.

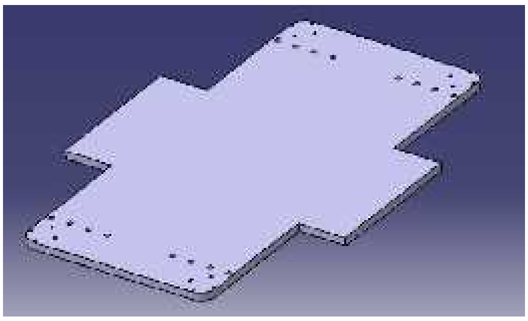


Figure 3.8: the base plat of robot

Fixed plate

This plate shown in Figure 3.9used to hold the carrying mechanism, and it have manyholes that are used to fixed the bearing holder, the dimension for this plate is the same of base plate.

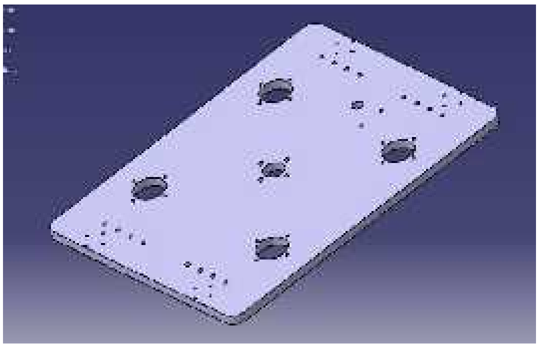


Figure 3.9: Fixed plate

Movement plate

In Figure 3.10show.It is the upper face for the robot that used to put the load onto the robot, it is made from Aluminum alloy, the dimension of this plate is 600mm × 820mm and the thickness is 20mm.

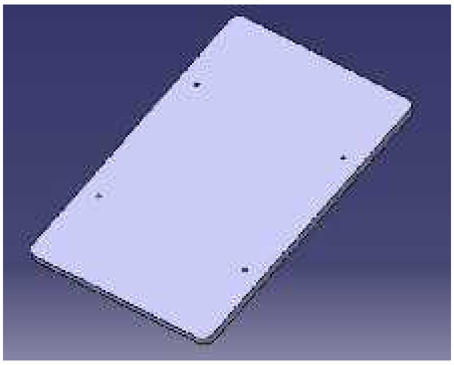


Figure 3.10: Movement plate

Tube

This tube show in Figure 3.11is built from Aluminum alloy, it is made to make a distance between the base plate and the fixed plate, and fixed them together.

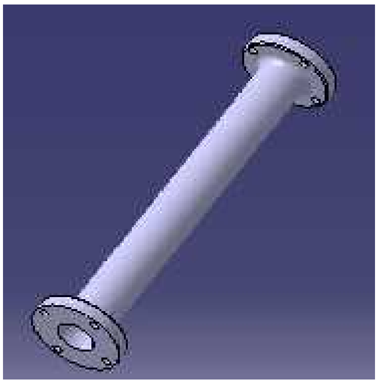


Figure 3.11: Tube

Motor Plate

This plate in Figure 3.12is used to fix the motor at the vertical position, this plate is made formAluminum alloy with more stiffness because it carries whole weight of robot. The dimension for motor plate is 260mm ×140mm and thickness 20mm.

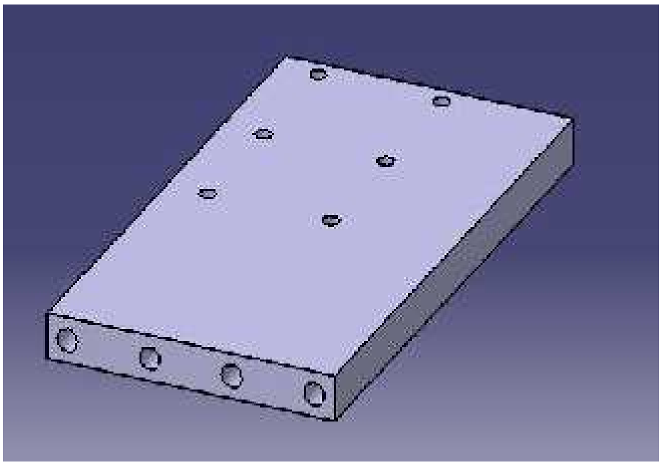


Figure 3.12: Motor plate

Bearings holder

The bearings holder in Figure 3.13 showmust be made formaluminum because when the bearing rotates it makes a small vibration that might crack the bearing holder if it was made from plastic.

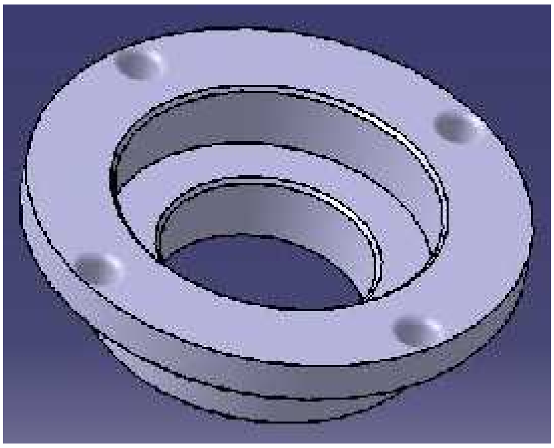


Figure 3.13: Bearing holder

3.1.3 Carrying mechanism

The carrying mechanism contains four parts, in this section will be discus two parts, Part A will be talking about component description and part B will talking about the calculation of power

Part A: component description

In this part the main gear, power gear, power screw and motor gear will be explained.

1- Main gear

The main gear is shown in Figure 3.14 has 500mm diameter, it was built from plastic to reduce the weight of robot. When this gear rotates clock wise it rotates the power gears in order to raise the movement plate, and when it rotated counter clock wise it rotates the power gears io order to lower the movement plate.

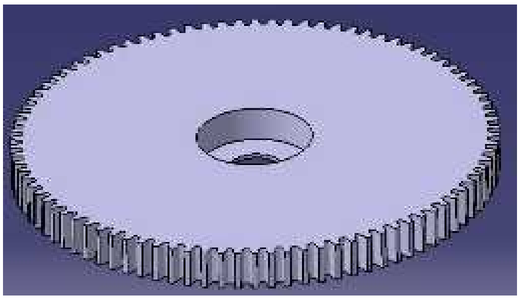


Figure 3.14: Main gear

2- Power gear

This robot has four power gears matching with the main gear, these gears has 105mm diameter and it is built form plastic. Each gear has inner teeth to connect to power screw. In Figure 3.15shows the power gear.

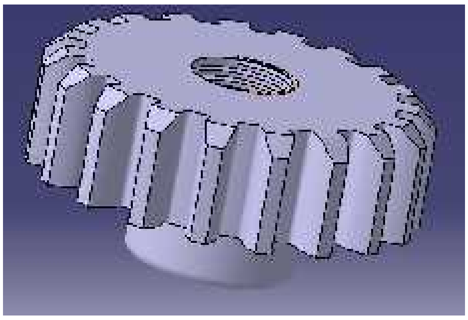


Figure 3.15: Power gear

3- Power screw

This robot has four power screw connect to power gear using inner teeth. The power screw show in Figure 3.16has 30 ×2.5 mm teeth diameter pitch and 250mm length. The material that will be use to made this screw is iron (1030).

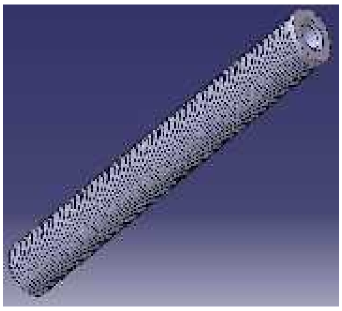


Figure 3.16: Power screw

4- Motor gear

This gear is the final part will be described in carrying mechanism. The motor gear show in Figure 3.17is connected directly with motor shaft and connected with main gear to transport thepower that produce from motor to power gear. It has a 60mm diameter, and the material will be used to made the motor gear is plastic.

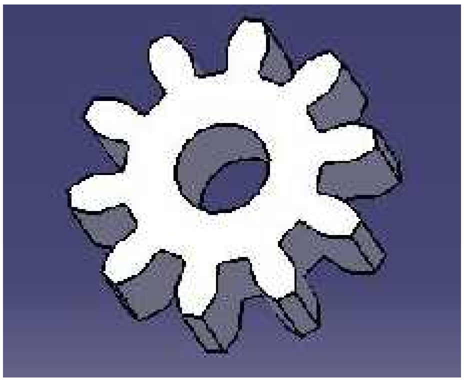


Figure 3.17: Motor gear.

Part B: Power calculation

This robot can carry up to one hundred and fiftyKg, that means, the load that is applied on each screw is 37.5Kg as shown inFigure 3.18.

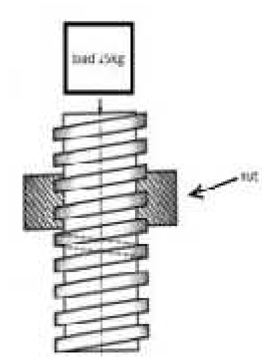


Figure 3.18: the load applied on each screw

Force of moving direction $F = mg\ \sin\theta + \mu\ \cos\theta$

Where:

F: force of moving direction.

m: mass of load/4.

g: acceleration of due to gravity.

θ: angle between normal force and load.

μ: coefficient friction.

$$F = 37.5 \times 9.81 \ \sin 90 + 0.05 \cos 90 \ = 367.87\ N$$

Screw preload $Fp = \frac{F}{3} = \frac{367.87}{3} = 122.62\ N$

load torque TL=$\frac{F \times pitch\ of\ screw}{2\pi\ efficient} + \frac{fricion \times Fp \times pitch}{2\pi}$

TL =$\frac{367.87 \times 2.5 \times 10^{-3}}{2 \times 3.14 \times 0.9} + \frac{0.3 \times 122.62 \times 2.5 \times 10^{-3}}{2 \times 3.14} = 0.117\ N.m$

Allow for a safety factor of 2 time

TL=TL × 2 = 0.117×2 = 0.235 $N.m$

0.235 $N.m$for each screw, the total torque = 4 ×0.235 = 0.94 $N.m$

Gear ratio

=$\frac{number\ of\ teeth\ of\ motor\ gear}{number\ of\ teeth\ big\ gear} \times \frac{number\ of\ teeth\ big\ gear}{number\ of\ teeth\ small\ gear} = \frac{number\ of\ teeth\ of\ motor\ gear}{number\ of\ teeth\ small\ gear} = \frac{10}{19} =$

0.52

3.1.4 Mechanical analysis

In this section will be make analysis of whole components of robot by use computer software using (ANSYS workbench).

The load will be analyzed about 2000N as a normal force applied to each part of robotseparately.

Figure 3.19 shows the total deflection for the movement plate.Appendix B explain the total analysis for this plate. Where the maximum deflection is shown in the red portion and equals 0.45383µm.

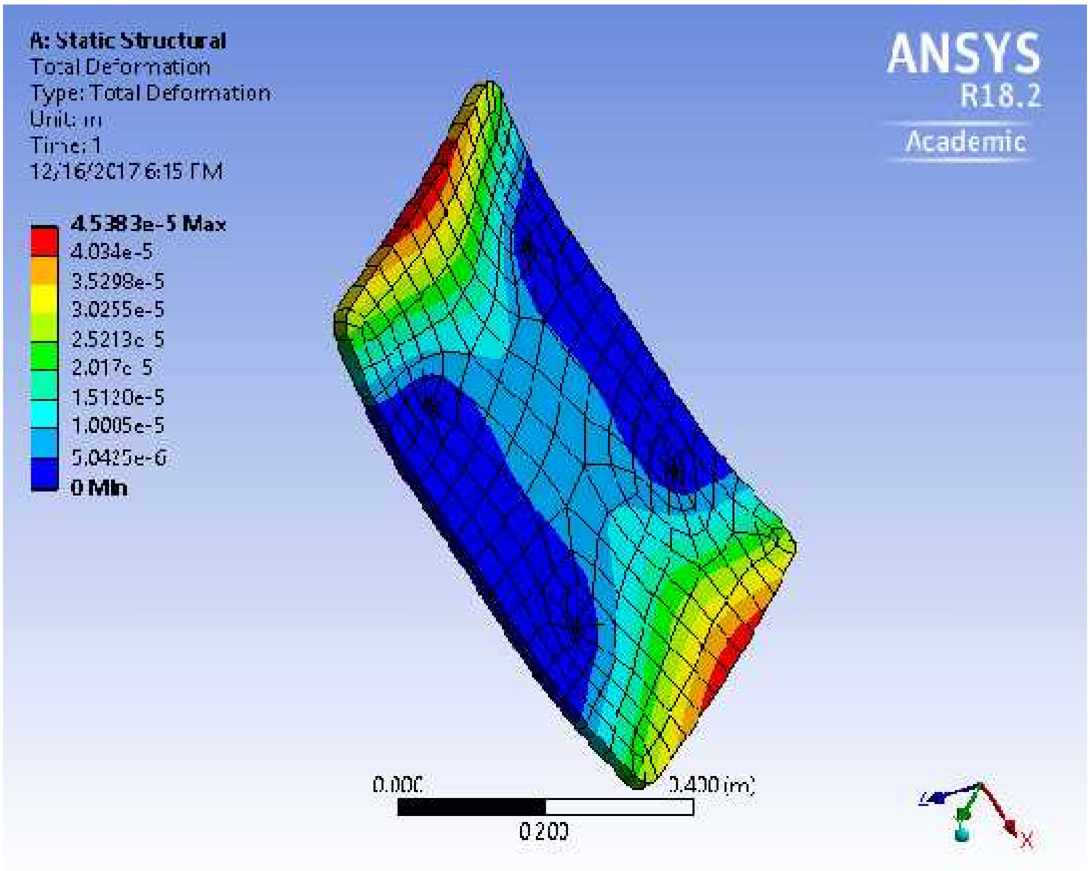


Figure 3.19: The total deflection for movement plate.

Figure 3.20 shows the deflection analysis for the movement plate. An appendix C explain, the total analysis. Where the maximum deflection is shown in the red portion and equals 0.00012038m.

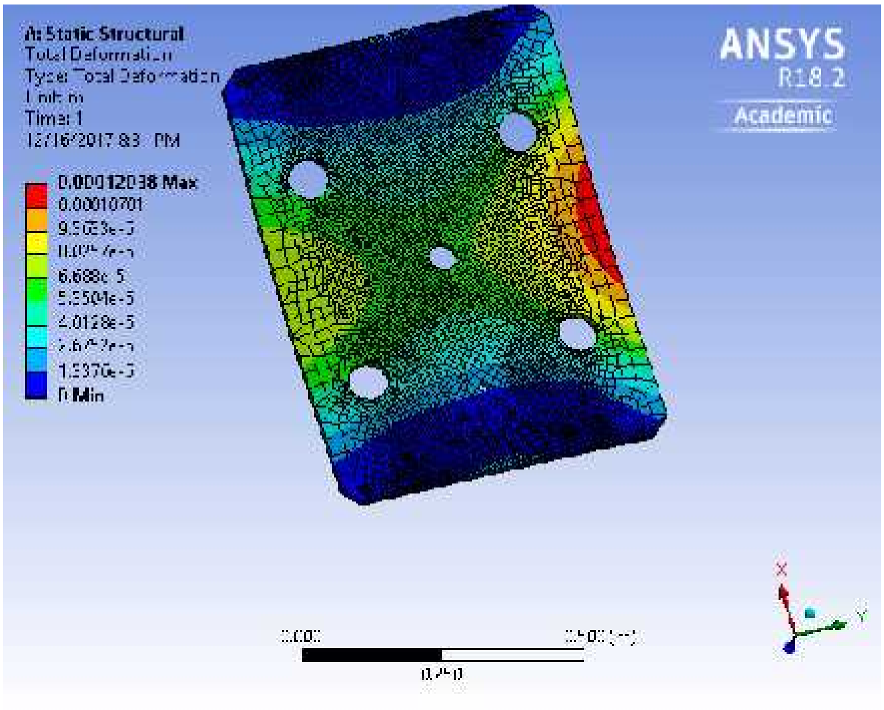


Figure 3.20: the total deflection for the movement plate.

Figure 3.21 shows the total deflection for each screw, AppendixD will explain the total analysisfor this screw.

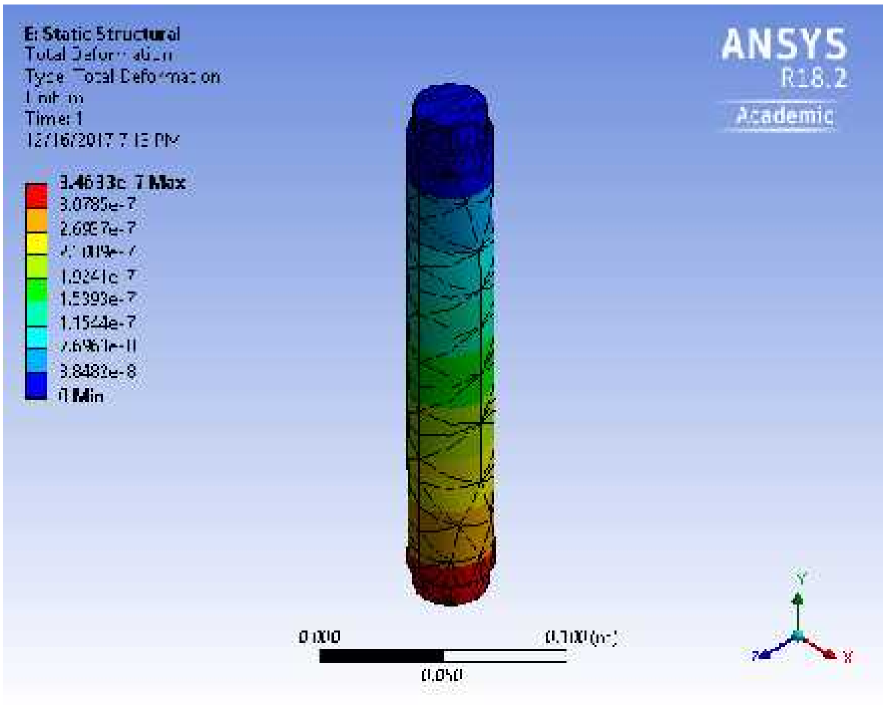


Figure 3.21: total deflection for the screw.

Figure 3.22 shows the total dereliction for the motor and motor plate. Where the maximum deflection is shown in the red portion and equals 5.4715µm. Appendix E will explain the total analysis.

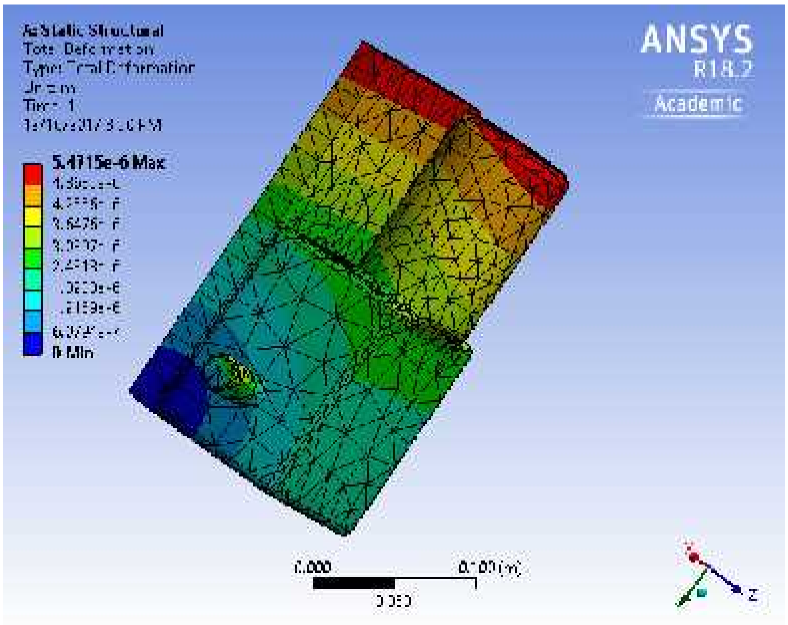


Figure 3.22: total deflection for motor and motor plate.

Figure 3.23 shows the total deflection for the tube. Where the maximum deflection is shown in the red portion and equals 0.11648µm. Appendix F will show the total analysis for the tube.

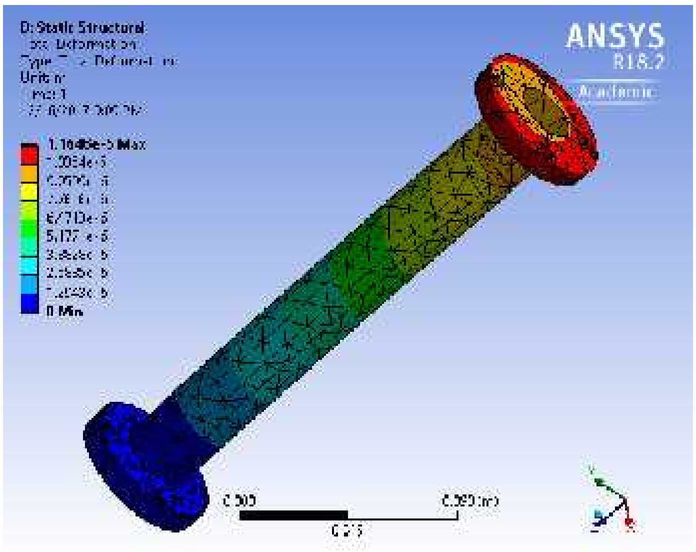


Figure 3.23: total deflection for the tube.

3.2 Electrical Design

This section willdiscussthe electrical design, Figure 3.24shows the wiring diagram for the robot, the electrical components will be explained in details in chapter five.

The robot used a 24V battery as power supply and two Arduino Mega as controllers, one of them was used as master controller connected to the motor drivers and to the Wi-Fi module, while the other Arduino was used assub controller connected to the sensors and encoders, which send the commands to the master controller.

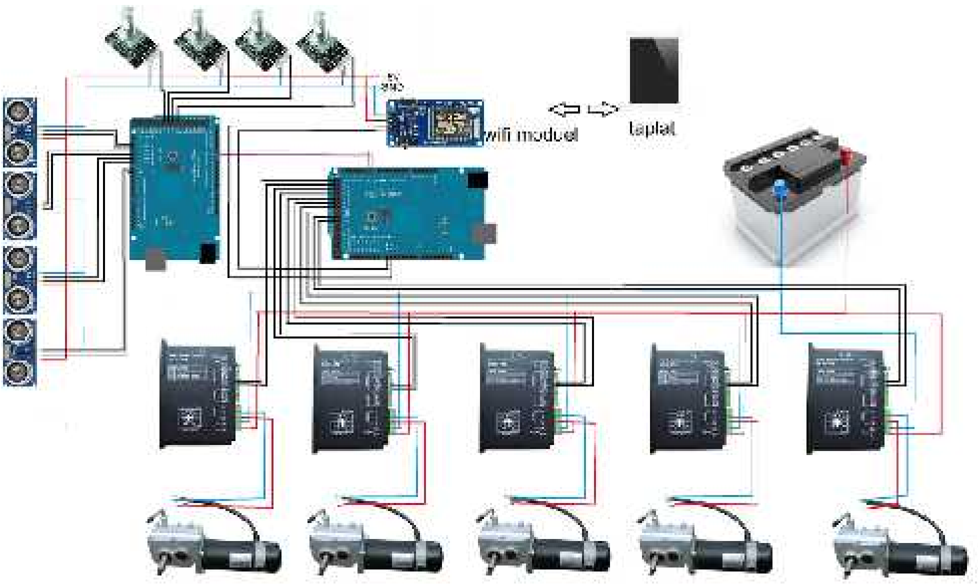


Figure 3.24: Electrical design

Chapter 4

Mathematical Model

4.1 Kinematics

When Mecanum wheels are actuated, the angled peripheral rollers translate a portion of the force in the rotational direction of the wheel to a force normal to the wheel direction.

Depending on each individual wheel direction and velocity, the resulting combination of all these forces produce a total force vector in any desired direction thus allowing the platform to move freely in the direction of the resulting force vectorwithout changing of the wheels themselves (Figure 4.1).

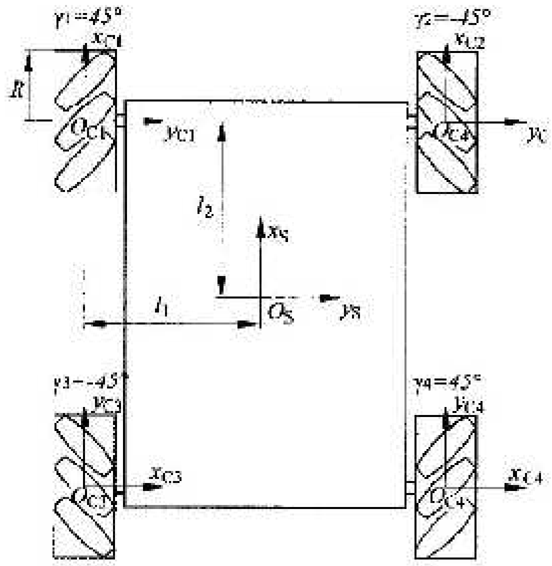


Figure 4.1: Kinematics of a WMR with Mecanum wheels

WMR: wheeled mobile robots.

R: The radiuses of mecanum wheels.

 : angle occurring between the axis of own rotation of the wheel and the axis of rotation of the roller equal in mecanum wheels 45 º.

Os: center point of robot.

Oc1:center point of wheel number one.

Oc2:center point of wheel number two.

Oc3:center point of wheel number three.

Oc4:center point of wheel number four.

L1:the distance between the center of robot and the center of wheel in x axis.

L2:the distance between the center of robot and the center of wheel in y axis.

ωi: angular velocity of wheel where i denotes the number of the wheel (i = 1, 2, 3, 4).

β\`: angular velocity of robot about center point.

Vx : velocity in x direction.

Vy :velocity in y direction.

The description of kinematics of the WMR in the case under consideration can also be presented in the form of the following equations.

$$Vx-Vy-\beta`(L1+L2)-\omega 1*R=0 \quad (4.1)$$

$$Vx+Vy+\beta`(L1+L2)-\omega 2*R=0 \quad (4.2)$$

$$Vx+Vy-\beta`(L1+L2)-\omega 3*R=0 \quad (4.3)$$

$$Vx-Vy+\beta`(L1+L2)-\omega 4*R=0 \quad (4.4)$$

These equations are equations of holonomic (geometric) constraints. Therefore, the WMR described with the use of the mentioned kinematic equations, is a holonomic object.

For this case it is also possible to present a solution of an inverse kinematics problem of the following relationships.

$$(Vx-Vy-\beta`(L1+L2))\frac{1}{R}=\omega 1 \quad (4.5)$$

$$(Vx+Vy+\beta`(L1+L2))\frac{1}{R}=\omega 2 \quad (4.6)$$

$$(Vx+Vy-\beta`(L1+L2))\frac{1}{R}=\omega 3 \quad (4.7)$$

$$(Vx-Vy+\beta`(L1+L2))\frac{1}{R}=\omega 4 \quad (4.8)$$

This equation can be presented in the form of a relationship presented below

$$\omega`=J*Vs \quad (4.9)$$

Vs: velocity

Where

$$\dot{\omega}=\begin{matrix}\dot{\omega}1\\ \dot{\omega}2\\ \dot{\omega}3\\ \dot{\omega}4\end{matrix} \quad (4.10)$$

$$J=\frac{1}{R}\begin{matrix} 1 & -1 & -(L1+L2) \\ 1 & 1 & (L1+L2) \\ 1 & -1 & -(L1+L2) \\ 1 & 1 & (L1+L2) \end{matrix} \quad (4.11)$$

$$Vs=\begin{matrix} Vx \\ Vy \\ \dot{\beta} \end{matrix} \quad (4.12)$$

$$\begin{matrix} \dot{\omega}1 \\ \dot{\omega}2 \\ \dot{\omega}3 \\ \dot{\omega}4 \end{matrix} = \frac{1}{R}\begin{matrix} 1 & -1 & -(L1+L2) \\ 1 & 1 & (L1+L2) \\ 1 & 1 & -(L1+L2) \\ 1 & -1 & (L1+L2) \end{matrix} \cdot \begin{matrix} Vx \\ Vy \\ \dot{\beta} \end{matrix} \quad (4.13)$$

In order to solve a forward kinematics problem, an inversion operation of matrix J should be performed. Matrix J is a rectangular matrix, therefore in order to perform its inversion will use the Moore-Penrose theorem on inversion of rectangular matrices. Once the mentioned theorem is applied, the following relationship

$$J^{-1}= (J \quad * J)^{-1} * J \quad (4.14)$$

$$J^{-1} = \frac{R}{4}\begin{matrix} 1 & 1 & 1 & 1 \\ -1 & 1 & 1 & -1 \\ \frac{-1}{(L1+L2)} & \frac{1}{(L1+L2)} & \frac{-1}{(L1+L2)} & \frac{1}{(L1+L2)} \end{matrix} \quad (4.15)$$

The solution of a forward kinematics problem can be received from the following relationship

$$Vs = J^{-1}\ \omega` \quad (4.16)$$

It is a source for the following equations

$$Vx= (\frac{R}{4})[\ \omega1 + \omega2 + \omega3 + \omega4] \quad (4.17)$$

$$Vy= (\frac{R}{4})[\ -\omega1 + \omega2 + \omega3 - \omega4] \quad (4.18)$$

$$\dot{\beta} = (\frac{R}{4(L1+L2)})[-\omega1 + \omega2 + \omega3 - \omega4] \quad (4.19)$$

4.2 Dynamics of a WMR with Mecanum wheel

Lagrangian formalism was used in order to obtain dynamic equations of motion of the WMR. Lagrange equations of the second kind for the described holonomic object.

$$\frac{\mathrm{d}}{\mathrm{dt}}\ \frac{\partial k}{\partial \omega i}\ -\frac{\partial K}{\partial \theta i}=Ti \tag{4.20}$$

$$K=\frac{1}{2}m\ \ Vx^2+Vy^2\ \ +\frac{1}{2}Iz\dot{\beta}^2+\frac{1}{2}Iw\cdot\sum_{i=0}^{4}\omega i^2 \tag{4.21}$$

Where

K: kinetic energy.

m: mass of robot.

Ti: is the torque of the wheel where i denotes the number of the wheel (i = 1, 2, 3, 4).

Vx: velocity in x direction.

Vy: velocity in y direction.

ωi: angular velocity of wheel where i denotes the number of the wheel (i = 1, 2, 3, 4).

β`: angular velocity of robot about center point.

Iz: moment of inertia of the vehicle around the z axis.

Iw: moment of inertia of the wheel around the center of revolution.

the potential energy U of this system is equal to zero.

In summary, the equation of motion is as follows:

$$M\cdot\dot{\omega}+D\cdot\omega=Ti=n\cdot Tm \tag{4.22}$$

Where

M: inertia matrix in equation (4.23).

D: is the coefficient matrix related to viscous friction in equation (4.24).

$$M=\begin{matrix} AB & -B & B & A-B \\ -B & AB & A-B & B \\ B & A-B & AB & -B \\ A-B & B & -B & AB \end{matrix} \tag{4.23}$$

D=Diag ($D1 \quad D2 \quad D3 \quad D4$) (4.24)

D1= viscous friction of wheel number one.

D2= viscous friction of wheel number two.

D3= viscous friction of wheel number three.

D4= viscous friction of wheel number four.

Where

$A = \frac{mR^2}{8}$, $B = \frac{IzR^2}{16*(L1-L2)}$

AB = A + B + Iw

m: mass of robot .

R: The radiuses of mecanum wheels.

Iz: moment of inertia of the vehicle around the z axis.

Iw: moment of inertia of the wheel around the center of revolution.

L1: the distance between the center of robot and the center of wheel in x axis.

L2: the distance between the center of robot and the center of wheel in y axis.

Table 4.1:Physical parameters

Variables	Values of parameters
Mass of the robot :m	218 (kg)
R: Radius of the wheel	0.1275(m)
n: Planetary gear ratio	32
L1, L2	0.25(m),27(m)
D: viscous friction	15(Nms/rad)
Iz: Moment of inertia of robot	12.2(kg m^2)
Iw: Moment of inertia of wheel	0.026((kg m^2)

A=0.44, B=0.023, AB=0.489, A-B=0.417

$$M=\begin{matrix} 0.489 & -0.023 & 0.023 & 0.419 \\ -0.023 & 0.489 & 0.419 & 0.023 \\ 0.023 & 0.419 & 0.489 & -0.023 \\ 0.419 & 0.023 & -0.023 & 0.489 \end{matrix}$$

$$D=\begin{matrix} 15 & 0 & 0 & 0 \\ 0 & 15 & 0 & 0 \\ 0 & 0 & 15 & 0 \\ 0 & 0 & 0 & 15 \end{matrix}$$

$$M \cdot \dot{\omega} + D \cdot \omega = Ti = n \cdot Tm$$

$$\begin{matrix} 0.489 & -0.023 & 0.023 & 0.419 \\ -0.023 & 0.489 & 0.419 & 0.023 \\ 0.023 & 0.419 & 0.489 & -0.023 \\ 0.419 & 0.023 & -0.023 & 0.489 \end{matrix} \cdot \begin{matrix} \dot{\omega}1 \\ \dot{\omega}2 \\ \dot{\omega}3 \\ \dot{\omega}4 \end{matrix} + \begin{matrix} 15 & 0 & 0 & 0 \\ 0 & 15 & 0 & 0 \\ 0 & 0 & 15 & 0 \\ 0 & 0 & 0 & 15 \end{matrix} \cdot \begin{matrix} \omega1 \\ \omega2 \\ \omega3 \\ \omega4 \end{matrix} = \begin{matrix} T1 \\ T2 \\ T3 \\ T4 \end{matrix}$$

A= $-M^{-1} \cdot D$

B= nM^{-1}

C= diag($I1$ $I2$ $I3$ $I4$)

$$A=\begin{matrix} -196.8 & -123.9 & 123.9 & 180.3 \\ -123.9 & -196.8 & 180.3 & -123.9 \\ 123.9 & 180.3 & -196.8 & 123.9 \\ 180.3 & 123.9 & -123.9 & -196.8 \end{matrix}$$

$$B=\begin{matrix} -6300 & -3900 & 3900 & 5700 \\ -3900 & -6300 & 5700 & 3900 \\ 3900 & 5700 & -6300 & -3900 \\ 5700 & 3900 & -3900 & -6300 \end{matrix}$$

$$C=\begin{matrix} 0.026 & 0 & 0 & 0 \\ 0 & 0.026 & 0 & 0 \\ 0 & 0 & 0.026 & 0 \\ 0 & 0 & 0 & 0.026 \end{matrix}$$

Matlab simulation

A block diagram without controller was made and it results a large amount of steady state error, so a robust tracker controller was made in order to solve this problem. Figure 4.2 shows the controller for the omi-directional mobile robot, the respone for controlled system can be found in figure 4.3.

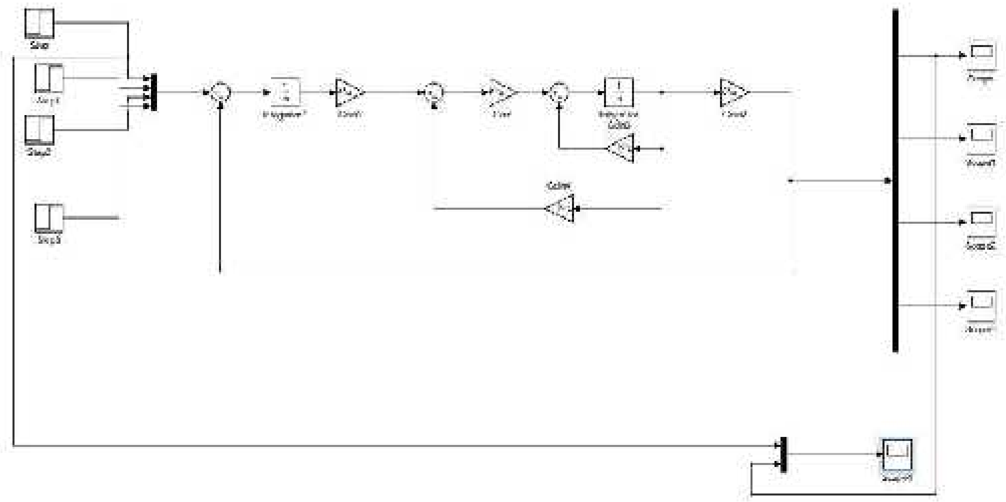


Figure 0.2: Block diagram for control system

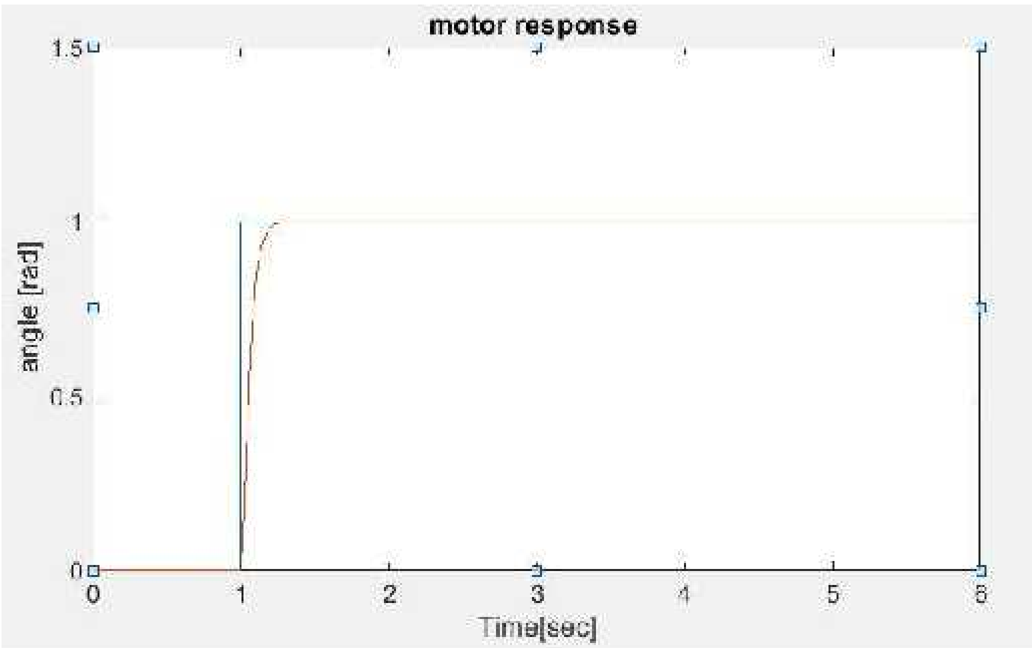


Figure 0.3: Control system response

Chapter 5

Components Selection

This chapter explains the components, and shows the function for each component.

5.1 Mechanical Components

A mechanical device has parts that move when it is working, often using power from an engine or from electricity, this section will be explain these mechanical elements.

5.1.1 Gears selection

This robot will use a gear to transport the power from the DC motor to the wheel or to the plat that carry the load, the wheelconnected directly tothe DC motor usingtwo small gears the ratio between gear is unity (spur gear)Figure 5.1 shows the gear, this gear using to transport the torque and speed from motor to the wheel without any change.

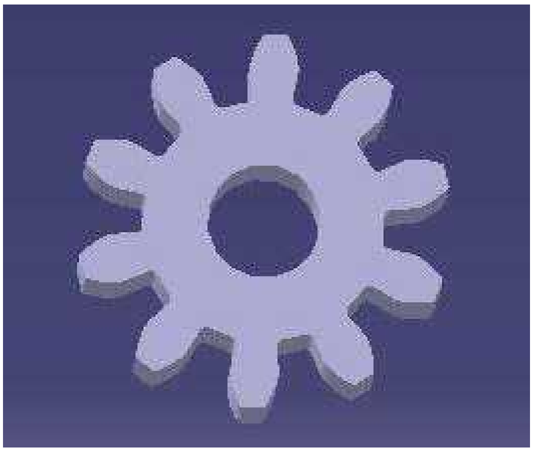


Figure 5.1: wheel gears

To carry the load the robot need the gears to increase the torque, Figure 5.2show the main gear that connects to four primary gears shown in Figure 5.4, this gears take the power from motor by driver gear (shown in Figure 5.4) connect to the main gear.Figure 5.5show the mechanism to carry the load.

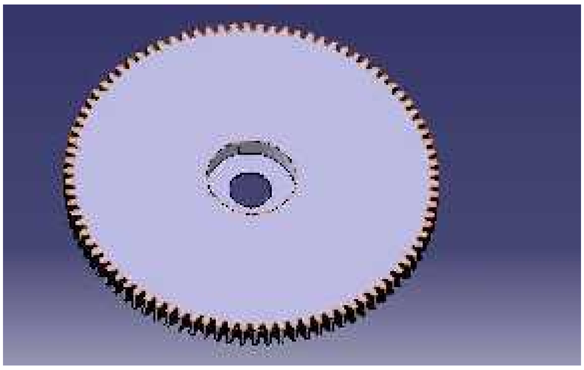


Figure 5.2: main gear

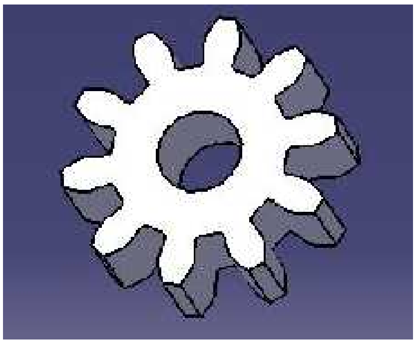


Figure 5.3: Driver gear

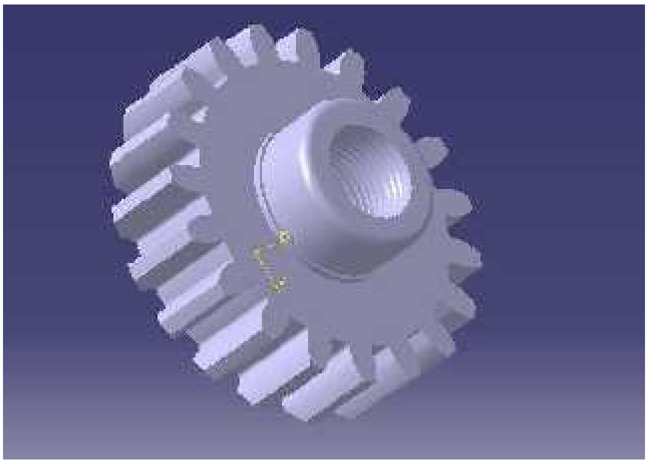


Figure 5.4: primary gears

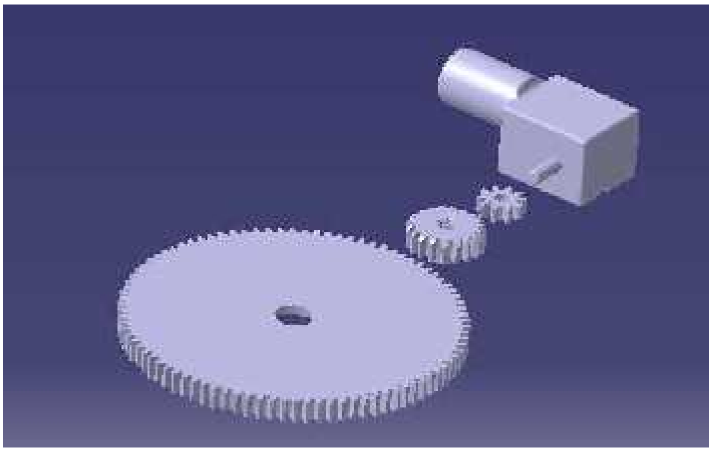


Figure 5.5: carrying load mechanism

5.1.2 Material selection

The body of the robot will be made from aluminum because ithas low weight and strong structures. Table 5.1 show the mechanical properties for Aluminum.

Table 5.1: Mechanical properties of aluminum

Mechanical properties	Metric unit
Hardness	12
Density	2.70 g/cc
Tensile Strength, Ultimate	45.0 MPa
Tensile Strength, Yield	10.0 MPa
Shear Strength	34.0 MPa
Modulus of Elasticity	62.0 GPa
Shear Modulus	25.0 GPa

The gears will be made from plastic because this material have good mechanical properties. Table **5.2** shows some of mechanical properties for plastic.

Table 5.2: Mechanical properties of plastic

Mechanical properties	Metric unit
Density	١٣٨٠ Kg/m^3
Young's modulus	2900-3300Mpa
Tensile Strength	50-80Mpa
Elongation at break	20-40%
Impact strength	2-5KJ/m^2

5.1.3 Robot's wheel

One of the important robot's features is to move to many direction (Figure 2.1), Mecanum wheel achieves the movements required from the robot. Figure 5.6show theMecanum wheel.

Figure 5.6: Mecanum wheel

5.1.4 Bearing

In this robot will be use bearing at 45degrees offsite in rolling position, this offsite make bearing affords more lode applied at it, Table 5.3 show the bearing details. The appendix A will explain all perimeter for this bearing.

Table 5.3: Bearing mechanical properties

Boundary dimension (mm)						Basic load rating				Limiting speed(min^{-1})	
d	D	T	B	C	r	C_r [N]	C_{0r} [N]	C_r [kgf]	C_{0r} [kgf]	Grease	Oil
45	68	15	15	12	0.6	34500	50500	3550	5150	5000	6700

5.2 Electrical Components

This section will explain each electrical component which consists of the robot.

5.2.1 Motor selection

The robot will be use the DC motor (as shown in Figure **5.7**) to care the load, the robot has four motors connected to each wheel to make omni direction motion, this motor will drive on 24 VDCand 420W power.

Figure 5.7: DC motor

5.2.2 Motors Driver

To get the omni motion it will need to controlled the speed of each motor, then it will need driver for each motor, the driver it will be select about the motor current, the chair wheel motor has current of 17.5A as a full load current, then it will need a driver matches to these motors. Figure 5.8show 20A driver with 24VDC. The robot need five drivers.

Figure 5.8: motors driver

5.2.3 Arduino

Arduino mega it will controlled all function the robot do it, It has 54 digitalinput/output pins, 16 analog inputs, a 16 MHz crystal oscillator, Operating Voltage 5V, Input Voltage (limits) 6-20V, DC Current per I/O Pin 40Ma, Flash Memory 128 KB of which 4 KB used by bootloader and Clock Speed 16MHz, It contains everything needed to support the microcontroller. All of these features make Arduino mega shown in Figure 5.9 the correct controller for the robot. The robot will need two Arduino mega to control it.

Figure 5.9: Arduino mega

5.2.4 Encoder

An incremental encoder generates a pulse for each incremental step in it's rotation. Although the incremental encoder does not output absolute position, it can provide high resolution. Figure 5.10show incremental encoder that robot need to detect the position and speed for each motor.

Figure 5.10: Incremental Encoder

5.2.5 Batteries

The voltage will robot need it is 24VDC then it will need tow battery with 12VDC connected at series form, when all function of robot are at the run mood, it need about 100Ah, so they need a battery with high capacity.Figure 5.11 show battery with 75 Ah capacity, the dimension of this battery is 260mm x 168mm x 233mm.

Figure 5.11: 12V DC Battery

Battery calculation

The current for input and out pins:

39 pins were used as input and output.

40 mA for each pin.

Total current for pins= 40*39

= 1560mA

The current for serial pins:

8 pins were used as serial.

50mA for each pins.

Total current for serial pins=50*8

400mA

The current for motor:

5 motor were used.

10A for each motor.

Total current for motors=5*10

50A

The ultrasonic sensors need 75mA

The total current for the robot:

1560mA+400mA+50A+75mA=52.35A

The power for sensor and microcontroller:

p=I*v

p=2.035A*5V

p= 10.175W

The power for motors:

p= 50A*12V

p= 600W

Total power = 600+10.175

610.175W

The energy consumption in watt-hour for the robot when the robot work one hour:

E = p* T

E = 610.175*1

E = 610.175W.h

So to run the robot for one hour at full load, a 12V batteries with 60 Ah capacity must be used.

The total power for the battery equals 720W, so the total power for the battery is larger than the total power needed, that’s why the 12V battery with 60 Ah capacity and current was selected

5.2.6 Color sensor

Robot have a line follower application, to follow the line it need a sensor can distinguish between colors, the sensor can do this is TCS3200Figure 5.12 show color sensor that will use in robot.

Figure 5.12: TCS3200 Color Sensor

5.2.7 Ultra-sonic sensor

Ultra-sonic sensor used to detect everybody around the robot to protect against collisions with objects and worker, it need four sensor bulged on the robot to detect maximum degree around it, Figure 5.13HC-SR04 Ultrasonic it will be use in this robot because HC-SR04 provides the ranging accuracy can reach to 3mm. Table 5.4 explain some of Electric Parameter for HC-SR04.

Table 5.4: Electric Parameter for HC-SR04

Working Voltage	DC 5 V
Working Current	15mA
Working Frequency	40Hz
Max Range	4m
Min Range	2cm
Measuring Angle	15 degree
Trigger Input Signal	10uS TTL pulse
Echo Output Signal	Input TTL lever signal and the range in proportion
Dimension	45*20*15mm

Figure 5.13: HC-SR04 Ultrasonic sensor

After designing the robot and selecting the suitable components and taking all the previous steps mentioned earlier in consideration, the final shape for the fabricated robot in this project can be shown in Figure 5.14.

Figure 5.14: The final fabricated robot

Chapter 6

implementation

6.1 Hardware

6.1.1 Mechanical hardware

6.1.2 Electrical hardware

6.2 software

6.2.1 Mobile application

6.2.2 Microcontrollers code

6.1 Hardware

This section will discuss the fabrication and installation of the hardware components and parts, the mechanical hardware will discuss the frame and the wheels of the robot, while the electrical hardware will discuss the components and the connection circuit.

6.1.1 Mechanical hardware

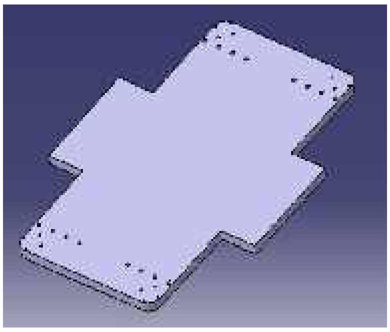
The best way to form the robot is to use aluminum metal to reduce weight as possible, this was done using lathe and CNC milling machines. The suitable thickness of the aluminum sheet is 20 mm. Both machines required 3D drawings for the project design, this was done by exporting "CATPart" extension files as shown inFigure 6.1.a.

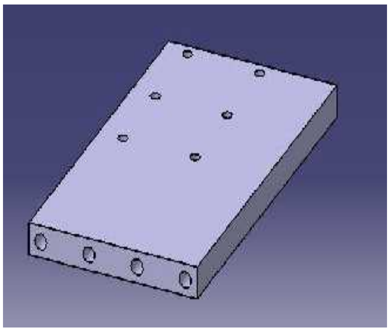
The frame of the robot consists of several fabricated parts: the base plate(Figure 6.1.a), the motor plate (Figure 6.1.b) which was connected to the base plate, the fixed plate(Figure 6.1.c) which was mounted over the motor plate, the connection between plates was done using 8 mm screws, the bearing holders (Figure 6.1.d) which were installed for both center and corner holes in the fixed plate, the power gears(Figure 6.1.e) which were added to the bearing holders, the main gear(Figure 6.1.f) which was mounted to the center power gear, the power screws(Figure 6.1.g) which were installed to the corner power gears, the motor gear(Figure 6.1.h) which was mounted to the 20 mm diameter hole in the fixed plate, the movement plate(Figure 6.1.i) which was attached to the power screws.

The robot has four wheels, each wheel consists of three main fabricated parts: two wheel flanges(Figure 6.1.j) attached to the motor which is installed to the motor plate, nine wheel rollers(Figure 6.1.k) installed in the flanges holes, and a wheel holder (Figure 6.1.l) to separate between the wheel flanges.

6.1.2 Electrical hardware

The commands are sent from the Smartphone application to the Wi-Fi module, then the Wi-Fi module sends the commands to the master controller via serial port, while the sub controller receives the sensors signals and sends it to the master controller also via serial port, the master controller will communicate with the commands from both the application and the sub controller in order to control the speed and direction for each motor. The circuit diagram for the electrical hardware is shown inFigure 6.2.


(a)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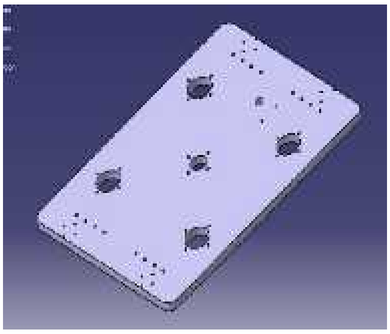
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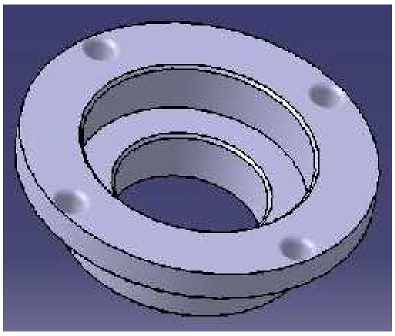
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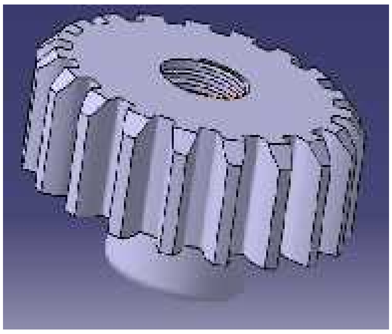
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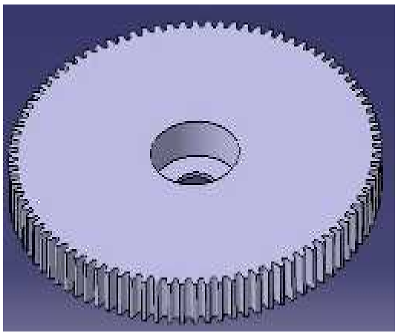
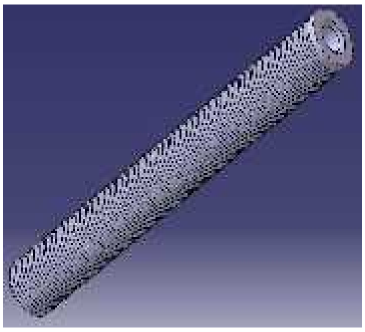
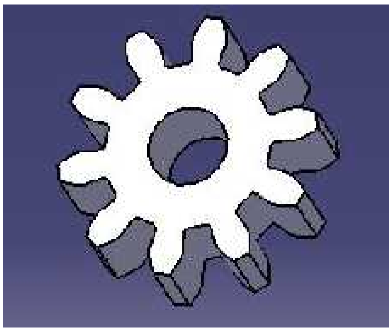
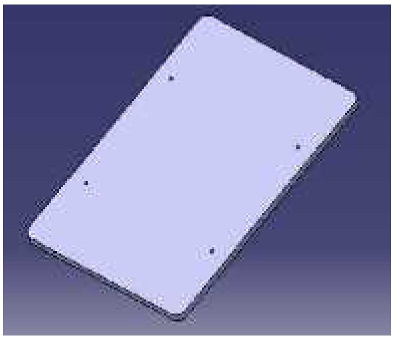
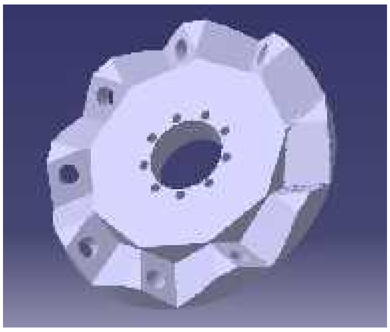
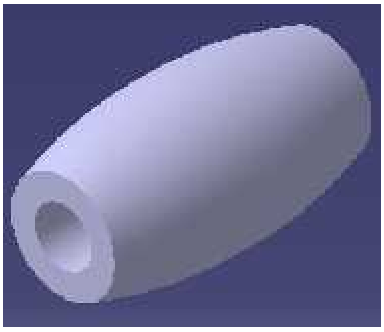

(f)


(g)


(h)


(i)


(j)


(k)

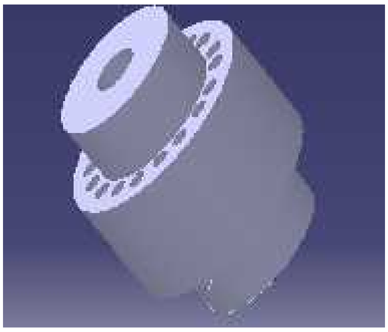

(l)

Figure 6.1: CATPart for the robot

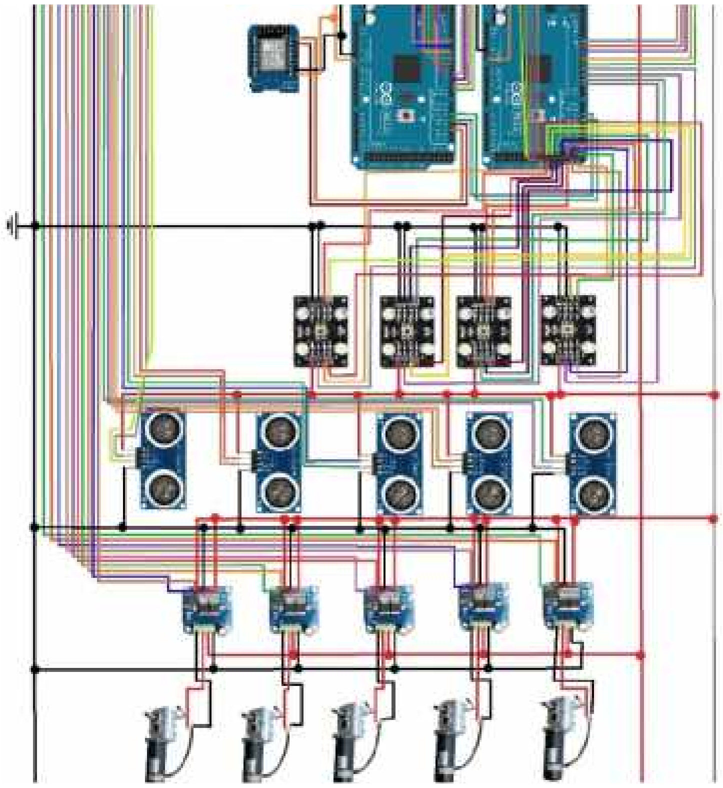


Figure 6.2: circuit diagram

6.2 software

After understanding the operation of the robot, and install all the mechanical and electrical components, it is easy to write the code. This section will describe the main functions in the Arduino and mobile application codes of this robot.

6.2.1 Mobile application

The App inventor program was used to write the application's code, Figure 6.3shows the user interface for the application.

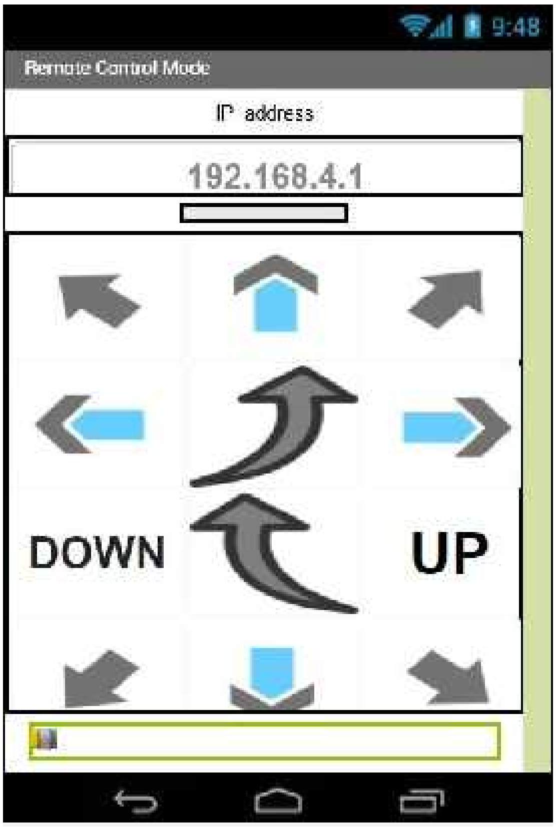


Figure 6.3: user interface for app

The App inventor use the block diagram code to coding the application, Figure **6.4** show the code for the Forward action in application, However, Appendix (G) contains the complete code.

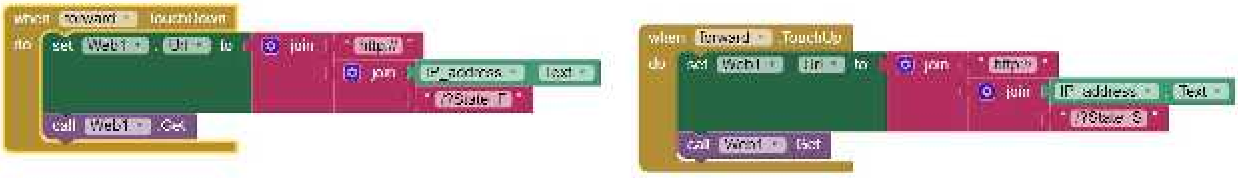


Figure 6.4: application code

6.2.2 Microcontrollers code

This robottwo Arduino mega for the control process.This section will describe the main functions in the Arduino code. However, Appendix (H) contains the complete code for all Arduinos.

The code of the master Arduino starts by defining theoutput and input pins for the system, as well as other variables that are used in the code.

The following code shows some pins definitions.

```
#define PWM1    2          // PWM for motor #1  for forward action     Mega(PWM2)
#define PWM2    3          // PWM for motor #1  for reverse action     Mega(PWM3)
#define PWM3    4          // PWM for motor #2  for forward action     Mega(PWM4)
#define PWM4    5          // PWM for motor #2  for reverse action     Mega(PWM5)
#define PWM5    6          // PWM for motor #3  for forward action     Mega(PWM6)
#define PWM6    7          // PWM for motor #3  for reverse action     Mega(PWM7)
#define PWM7    8          // PWM for motor #4  for forward action     Mega(PWM8)
#define PWM8    9          // PWM for motor #4  for reverse action     Mega(PWM9)
//MOTOR #5 IS THE MOTOR FOR CARING MECHAMICEM
#define PWM9    10         // PWM for motor #5  for forward action     Mega(PWM10)
#define PWM10   11         // PWM for motor #5  for reverse action     Mega(PWM11)

int command;               //integer command from Wifi module.
int command1;              //integer command from arduino mega.
int speedCar;              // robot speed
int R=0.110;               //wheel radius
int Vx;                    // The robot speed at X axis.
int Vy;                    // The robot speed at Y axis
int Wz;                    // The  rotation speed about Z axis.
int L1=0.3;                //distances between wheel axis and body center.
int L2=0.41;               // distances between wheel axis and body center.
int W1;                    // rotational speed for the first wheel.
int W2;                    // rotational speed for the second  wheel.
int W3;                    // rotational speed for the third wheel.
int W4;                    // rotational speed for the fourth wheel.
```

Code 6.1

The next step in the code, defines the pins setup. This operation is done for one time at the start of the code. It can set system homing in void setup, because it is also done for one time.

```
void setup() {

 pinMode(PWM1, OUTPUT);
 pinMode(PWM2, OUTPUT);
 pinMode(PWM3, OUTPUT);
 pinMode(PWM4, OUTPUT);
 pinMode(PWM5, OUTPUT);
 pinMode(PWM6, OUTPUT);
 pinMode(PWM7, OUTPUT);
 pinMode(PWM8, OUTPUT);
 pinMode(PWM9, OUTPUT);
 pinMode(PWM10, OUTPUT);

 Serial1.begin(9600);   // the serial that use to recive the command from Wi-Fi module.
 Serial2.begin(9600);   // the serial that use to recive the command from sub controller.

}
```

Code 6.2

After that, the main loop function is defined. This will be executed repeatedly every cycle.

Inthevoid loop for the master controller, first it calculates the rotational speed for each motor using the equation of motion for the robot.

```
void loop() {
  W1=(1/R)*(Vx+Vy-(L1*Wz)-(L2*Wz));
  W2=(1/R)*(Vx-Vy+(L1*Wz)+(L2*Wz));
  W3=(1/R)*(Vx-Vy-(L1*Wz)-(L2*Wz));
  W4=(1/R)*(Vx+Vy+(L2*Wz)+(L2*Wz));
```

Code 6.3

Then it receives the command form the WI-FI module that contains the robot action and the axis speed, this is in conjunction with receiving the command from sub controller to detect if any object is around it.

```
if(Serial1.available() > 0)
{
  command = Serial1.read();



   if  (command == 100||command1 !=0) {
    goAhead();

    Vx=speedCar;
    Vy=0;
    Wz=0;

   }
```

Code 6.4

As an example, if the command sent from the Wi-Fi module is the forward action command, The controller executes the function goAhead().

```
void goAhead(){


      analogWrite(PWM1, W1);
      analogWrite(PWM2, 0);
      analogWrite(PWM3, W2);
      analogWrite(PWM4, 0);
      analogWrite(PWM5, W3);
      analogWrite(PWM6, 0);
      analogWrite(PWM7, W4);
      analogWrite(PWM8, 0);
      analogWrite(PWM9, 0);
      analogWrite(PWM10, 0);

  }
```

Code 6.5

The second Arduino mega that is used as a sub controller, reads the value of the ultrasonic sensors and gives command to the master controller as following:

```
// Clears the trigPin
digitalWrite(trigPin1, LOW);
delayMicroseconds(2);

// Sets the trigPin on HIGH state for 10 micro seconds
digitalWrite(trigPin1, HIGH);
delayMicroseconds(10);
digitalWrite(trigPin1, LOW);

// Reads the echoPin, returns the sound wave travel time in microseconds
duration1 = pulseIn(echoPin1, HIGH);
```

Code 6.6

```
if(distance1<=50&&distance2<=50&&distance3<=50){

  Serial2.write(100);
}
```

Code 6.7

Chapter 7

Project Management

7.1Work Breakdown Structure

7.2 Schedule and Gantt chart

7.3 Budget and Costs

٧.٤ Design problems

This chapter will discuss the management and planning of the project. Firstly, it will talk about the division of the main system into subsystems and small components. Then, it will talk about the main tasks and time table. The final section will be about the Budget and table of costs.

7.1Work Breakdown Structure

The Work Breakdown Structure (WBS) is a tree structure which shows a subdivision of effort required to achieve an objective. It is a useful tool that provides the necessary framework for detailed cost estimating and guidance for schedule development.

The WBS of the omni-direction robot is shown in Figure 7.1, the system is divided into four levels as shown in the Figure. Each level has the same block color.

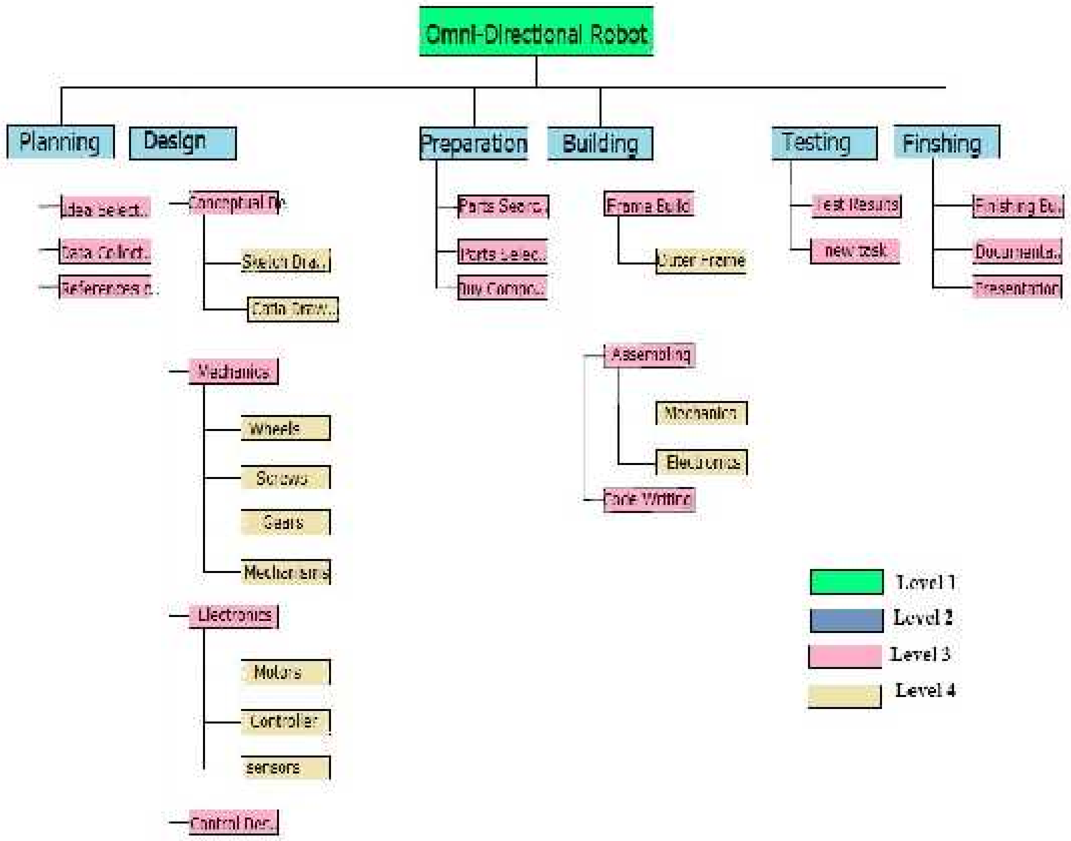


Figure 7.1: Work Breakdown Structure for omni-direction robot.

7.2 Schedule and Gantt chart

In order to achieve the main objective of this project, it is necessary to divide the work into several tasks as shown in Table 7.1.

Table 7.1: Tasks description for Omni-Direction Robot

	Task description
T1	Selection of Idea
T2	Collecting the Data
T3	Collecting References
T4	Conceptual design
T5	Mechanical design
T6	Electrical design
T7	Draw the mechanical design in Catia software
T8	Mathematical model
T9	Component selection
T10	Documentation
T11	Prepare the 1st presentation
T12	Buy the mechanical and electronic parts
T13	Build the project
T14	Assembling the mechanical and electronic parts of the system
T15	Write the Arduino code
T16	Test the result
T17	Correction the errors
T18	Documentation
T19	Prepare the final presentation

The Ganttchart is shown in Table 7.2, it shows the distribution of the tasks along thesecond semester 2017/2018.

Table 7.2: Gantt chart for the first semester.

Task/week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
T1	■	■	■	■												
T2				■	■	■										
T3						■	■									
T4						■	■	■								
T5								■	■	■	■					
T6								■	■	■	■					
T7										■	■	■	■			
T8											■	■	■	■		
T9													■	■	■	
T10								■	■	■	■	■	■	■	■	■
T11																■

The schedule of the second semester 2017/2018 tasks is shown in Table 7.3

Table 7.3: Gantt chart for the second semester.

Task/week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
T12	■	■	■	■	■	■										
T13				■	■	■	■	■	■	■	■					
T14										■	■	■	■			
T15								■	■	■	■	■	■			
T16														■	■	■
T17															■	■
T18												■	■	■	■	■
T19																■

7.3 Budget and Costs

The approximate cost of the required components and the number of each component is shown in Table 7.4. The total cost of this project is estimated below:

Table 7.4: Total cost of the

Part name	Quantity	Cost for each part(NIS)	Total (NIS)
Controllers	2	100	200
Gears	6	200	1200
Motors	5	1000	5000
Drivers	5	200	1000
Robot body and wheels	1	3000	3000
Sensors	7	100	700
Manufacturing	1	2000	2000

Total budget:13100(NIS)

٧.٤ Design problems

During building this project, The team faced many problems. These problems are:

1- Omni-directional motion.

The robot is able to move into many directions; right, left, forward, backward, …etc. So the wheels are important to produce all of these movements, then the robot needed a special wheel's design because the universal wheels cannot help to do these movements. Mecanum wheels are one of those wheels that can produce these movements.

2- Wheel design.

The first problemthat is oriented when designing the wheel is choosing the number of wheel's rollers, because the load that the wheel can carry depends on the number of rollers. Then the number of rollers that can achieves the desired goal of the robot is nine rollers. The second problem is the angle of rollers that allow to compact two flanges together, the angle that meets this desired is 22˚.

3- Carrying mechanism

Robot was carry the load up to one hundred and fifty Kg. So it was need a motor that has a correct torque with maximum input voltage 24V, the motors have these properties are wheels chair motors.

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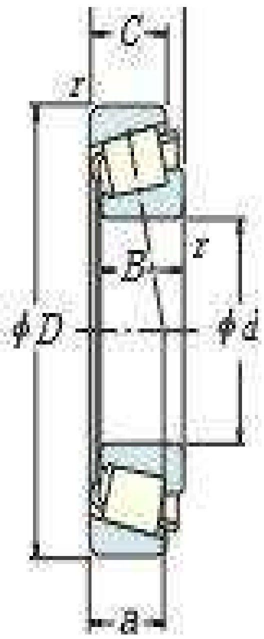
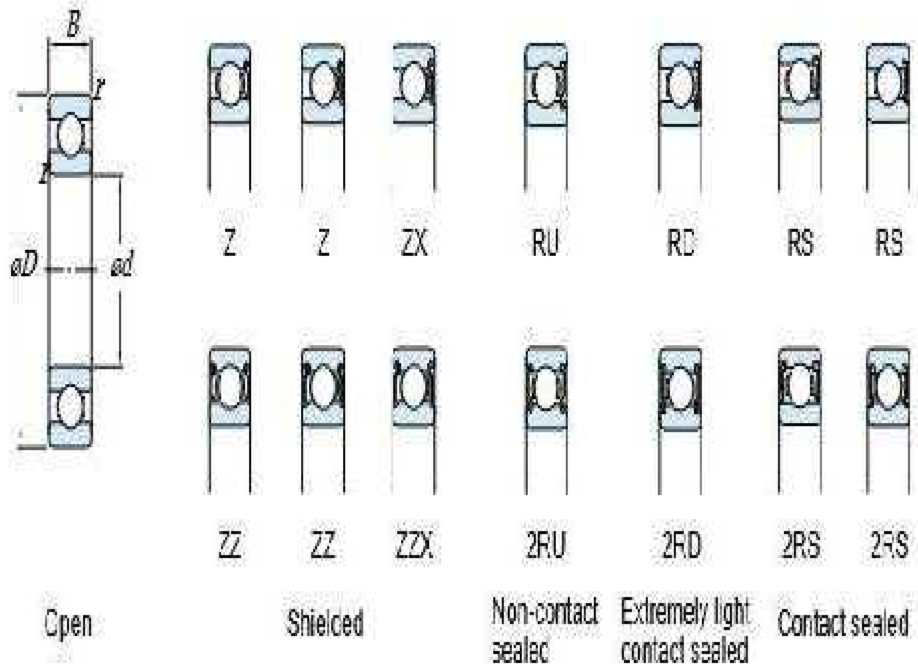
Appendix

Appendix A



Boundary Dimensions (mm)							Basic Load Rat	
							(N)	
d	D	T	B	C	Cone r min.	Cup r min.	C_r	C_{0r}
40	62	15	15	12	0.6	0.6	34 000	47 000
	68	19	19	14.5	1	1	53 000	71 000
	68	22	22	18	1	1	59 000	81 500
	75	26	26	20.5	1.5	1.5	78 500	101 000
	80	19.75	18	16	1.5	1.5	63 500	70 000
	80	24.75	23	19	1.5	1.5	77 000	90 500
	80	24.75	23	19	1.5	1.5	74 000	90 500
	80	32	32	25	1.5	1.5	107 000	137 000
	90	25.25	23	20	2	1.5	90 500	101 000
	90	25.25	23	18	2	1.5	84 500	93 500
	90	25.25	23	17	2	1.5	80 000	89 500
	90	25.25	23	17	2	1.5	80 000	89 500
	90	35.25	33	27	2	1.5	120 000	145 000
45	68	15	15	12	0.6	0.6	34 500	50 500
	75	20	20	15.5	1	1	60 000	83 000
	75	24	24	19	1	1	69 000	99 000
	80	26	26	20.5	1.5	1.5	84 000	113 000
	85	20.75	19	16	1.5	1.5	68 500	79 500
	85	24.75	23	19	1.5	1.5	83 000	102 000
	85	24.75	23	19	1.5	1.5	75 500	95 500
	85	32	32	25	1.5	1.5	111 000	147 000
	95	29	26.5	20	2.5	2.5	88 500	109 000



Boundary dimensions (mm) D	B	r min	Basic load ratings (kN) C_r	C_{0r}	Limiting speeds (min^{-1}) Grease lub. Open Z, ZZ RU, 2RU	(RD, 2RD)	(RS, 2RS)	Oil lub. Open Z	Bearing No. Open	Shielded ZZ	Sealed 2RU	2RD	2RS	(Refer.) Mass Open type (kg)
65	7	0.3	6.30	6.10	9 600	–	–	11 000	6810	ZZ	2RU	–	–	0.052
72	12	0.6	14.5	11.7	9 000	–	–	11 000	6910	ZZ	2RU	–	–	0.133
80	10	0.6	16.0	13.3	8 200	–	–	9 700	16010	–	–	–	–	0.130
80	16	1	21.8	16.6	8 400	–	4 800	9 900	6010	ZZ	2RU	–	2RS	0.251
90	20	1.1	35.1	23.3	7 100	6 400	4 600	8 500	6210	ZZ	2RU	2RD	2RS	0.453
110	27	2	62.0	38.3	6 100	5 500	4 100	7 300	6310	ZZ	2RU	2RD	2RS	1.07
130	31	2.1	83.0	49.5	5 500	–	–	6 600	6410	–	–	–	–	1.83
72	9	0.3	8.30	8.10	8 700	–	–	10 000	6811	ZZ	2RU	–	–	0.083
80	13	1	16.6	14.1	8 100	–	–	9 600	6911	ZZ	2RU	–	–	0.135
90	11	0.6	19.3	16.3	7 400	–	–	8 800	16011	–	–	–	–	0.250
90	18	1.1	28.3	21.2	7 600	–	4 300	8 900	6011	ZZ	2RU	–	2RS	0.335
100	21	1.5	45.4	29.4	6 300	–	4 100	7 600	6211	ZZ	2RU	–	2RS	0.607
120	29	2	71.6	45.0	5 600	–	3 700	6 700	6311	ZZ	2RU	–	2RS	1.37
140	33	2.1	100	62.3	5 000	–	–	6 000	6411	–	–	–	–	2.29

Appendix B