DESIGN AND MANUFACTUER OF AN OMNI-WHEEL ROBOT WITH A DUAL ARM MANIPULATOR

Hemin Jamal Mustafa

MASTER THESIS
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ABSTRACT

In the latest years, Autonomous Robots, which can operate using variety of different movement, have be developed manufactured and used in various occasions and occupations in this thesis a robot has been designed and created which uses Omni Wheels. Omni wheels robots are very common, since they do have the ability to move in any direction, and some are equipped with grippers or/and arms. A common problem that exists in such robots is that the robot's gripper is too short to reach items that are stored in high elevations, for example above a table. Given that most items are stored in higher places, the purpose of this research has been to design and create a robot that has large arms that can reach objects that are above its height without the need of expanding its body and without the risk of tripping over. Furthermore, it has been the objective of this research to equip this Omni robot with wireless radio capabilities. This wireless radio controlled capabilities would further enhance the function of the robot to obtain and transmit data from a remote position.

ÖZET

Çift Kollu Manipülatöre Sahip Omni Tekerlekli Bir Robotun Tasarımı ve İmalatı

Son yıllarda, çeşitli hareket kabiliyetine sahip Otonom Robotlar, farklı alanlarda kullanmak için üretilmiştir. Bu tezde Omni tekerlere sahip bir robot tasarlanmış ve üretilmiştir. Omni tekerli robotları çok yaygındır, çünkü herhangi bir yöne hareket edebilme yeteneğine sahiptirler ve bazıları kıskaçlar veya kollarla donatılmıştır. Bu tür robotlarda görülen yaygın bir problem, robotun tutucusunun, yüksek kotlarda depolanan öğelere ulaşmak için çok kısa olmasıdır. Bu araştırmanın amacı, gövdesini genişletmeye gerek kalmadan yüksekteki nesnelere ulaşabilen uzun kolları olan bir robot tasarlamak ve üretmektir. Ayrıca, bu robotu kablosuz iletişim yetenekleriyle donatmak bu araştırmanın amacı olmuştur. Kablosuz radyo frekans kontrollü yetenekler, robotun uzak bir konumdan veri alma ve iletme işlevini daha da artıracaktır.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

DOF	Degree Of Freedom
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
DH	Denavit-Hartenberg
DC	Direct Current
AC	Alternative Current
RPM	Revolutions Per Minute
MCU	Motor Control Application
IDE	Integrated Development Environment
GHz	Gigahertz
AFHSS	Adaptive Frequency-Hopping Spread Spectrum
PPM	Pulse-Position Modulation
PCM	Pulse-Code Modulation
DIR	Digital Instrumentation Range
PWM	Pulse Width Modulation
GND	Ground
IOT	Internet Of Things
PID	Proportional Integral Derivative
RF	Radio Frequency

LIST OF SYMBOLS

θ	Theta
α	Alpha
S	Sine
C	Cosine

1. INTRODUCTION

1.1. Background

In the past robots have been used primarily as a research field tool or as a hobby. However, their vast development in the recent years have enabled robots to be, used in a variety of occasions. One of the main challenges in the development of robots has been the limitation of their use. With the revolution of the IOT (Internet Of Things) and the latest smart technologies it has been a fact that many companies are starting to invest again in autonomous robots that are capable to move and often to interact with their environment. Autonomous robots can cover a need that IOT Devices cannot, they can and have the option to move. Today devices and equipment in locations such as in a house or in an office can be remotely managed and controlled. This could be, done by using sensors, which can transmit data throughout the day and night and allow the devises in these areas to be remotely controlled. Whilst such devices can cover a large area, their purpose is limited. On the other hand, an autonomous robot can have a generic purpose and cover every day's needs that are already known but also to cover new needs that may not have been predicted. Another important and useful advantage of autonomous robots is that they are capable to operate in areas that human cannot exist, or it is difficult to exist, such as a cliff, or a hazard area. Robots can be present to in such harsh and difficult environment, interact and even setup sensors and other devices. Additionally, today's robots are capable of using complex algorithm, which allow them to understand the space around them, avoid objects obstacles and position themselves in such way that will make them to interact with another objects and devises. While many robots are capable to go in such environments, the compatibility between robots varies for example, some robots are made for the sea or for the air others for smooth surfaces. In this report an Omni Robot will be studied and demonstrated. The world omni stands for every direction, in our case omni robot are robots that have omni wheels. Such wheels allow them to move in all direction even if they trip over. True to its name, an omni robot can go in every direction but also in almost all surfaces, it moves through difficult terrain and due to its size, it can reach places that humans cannot go or it is difficult to go. Additionally, since a robot is immune to poisoning or disease an omni robot can be used in contaminated places. Omni robots are defined by the nature of their wheels. Nevertheless the wheels are just one of the most important parts of the robots, in the latest recent years Omnis robots have been additionally equipped with other accessories, like sensors , cameras and grips. The sensors are used to take measurements and send data remotely back to a computer or a data logger. Additional sensors can be used for helping the omni robot to navigate throughout the place. Such sensor is the ultrasonic sensor that measures distance by sending an ultrasonic and measure the time that took the signal to come back, proximity sensors that are using light beams and sometimes a light sensor that is used to detect if ground exists. These data are and could be used by a main controller, in our case Arduino and help the robot to navigate and avoid collision. Sometimes cameras are used that for transmitting and/or capturing footage. Such omni can be used to transmit video from a difficult location for example from inside a pipe, this could aid the repairs, or it can be used as guards. Since the Omnis are equipped with a microcontroller, they can also use image recognition to automatically assent a case for example identify a human. Finally, some Omnis are equipped with tools that allow them to interact with the environment. A very common example is a grip, such grip can be used to catch, place, transfer and in some cases even use objects. The scientific community has shown a special interest to robot grips. According to this thesis, there are many robots that are equipped with grips, but in most cases the grips are small, and they can only operate in short heights. To solve this issue a tactic was employed that allowed the robot assents by enlarging the body and catch object in higher places. While this was a solution it has, some main drawbacks one of the main drawbacks is that this accenting was very slow. That makes the robot inefficient and slow. To solve this issue, we proposed a new type of Omni robot that is equipped with bigger grips that will allow catching and interacting with objects at a higher place without the need of assenting.

1.2. Motivation

According to our knowledge there are many omni robots that exist in the scientific community industry and even for hobbyist many of these robots have been extended far from the purpose of moving using omni wheels. The robot base that use omni wheels is serving as a very stable and able base, which can move in any directions. One of the main disadvantages of the omni base is that it can be slow, since not all the wheels are, rotating this can cause friction problem and slows down the robot's movement. Nevertheless, omni wheels are used very commonly in robotics with some very famous application such as robot

[1], that is used for educational purposes or for entertainment like qfix robot [2] that is a soccer robot. While such appearance are common, what is rarer is the use of omni robot with a gripper. A gripper increases the robot's usability and functionality far beyond interment or training. Such robots do exist and while they are rarer, they are still common. One of the common problems of such robots is that in most cases the height renders the gripper useless. To overpass such serious limitation, robots have been created so that they can assent and dissent. To do that, they used a special screw within the base, to assent and dissent the robot by fastening (winding) and unfastening the screw this allow the robot to extent its base to reach higher places. An issue that this robot had was speed. To safely unfasten the screw without the risk of tripping over, the speed must be very slow. In this report, we propose a new robotic design that will address this very problem. A robot with omni base which has large grips that could interact with objects at higher places. This design will address the problem of speed since our robot will be able to grab things from higher places without the need to assent.

1.3. Initial Work

Before embarking work on this new robot design, a research and a planning regarding the various part that can be used has been carried out. For this, a waterfall model approach has been used. The figure 1.1 shows Waterfall Model shape, While this approach is very famous in software engineering so and can be, an approach applied in many projects.

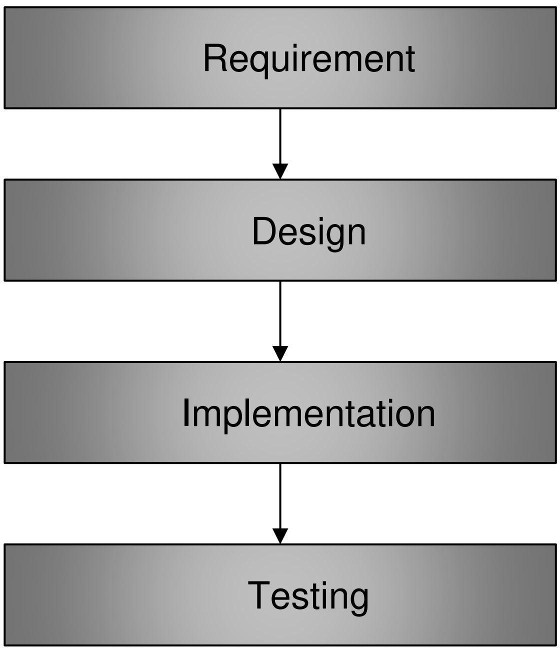

Figure 1.1 Waterfall Model.

At first, the robot requirements have to be captured as well as the functional and non-functional elements of the robot. This lead to note down and understand the needs of this project. This lead to move forward to the next stage, which was the design of this project. In the design stage the requirements were broken down and start to find ways to address each part of the project. Before the start of the new design a search was carried out within the existing literature and online resources to find current solutions that can address individual requirements. The research was done in a comprehensive way, this allowed and lead to divide and obtain theory, which has been used. As this search has been completed an understanding has been reached that this project should be divided into three main parts. The first part was the construction of the robot, the second was the integration of the physical part to the controller (wiring) the setup of the controller, power supply and the final part was the programming of the controller. The first two parts were completed in the following way. The robot was divided into 5 separated subparts; every single part has its own plan on how to acquire the resources and how to integrate with the main part. Thereafter the design were the controller should be seated was carried out, and finally the design of how the controller should be powered. As for the last part, a code in Pseudo code was created to understand how the algorithm should work before implementing the action solution. When the design was completed, the project moved forward into the implementation stage.

1.4. Goals and Requirements

The main goal was to create an Omni robot that could be able to interact with objects that are in various heights and positions. The robot deign had to overcome the classic problem associated with the Omni's robots with short grips, without compromising the robot's speed of action unlike the assenting robot. To do this there was several requirements that needed to be completed. These requirements can be divided to functional and non-functional requirements.

1.4.1 Functional Requirements

- **The Omni Robot must be able to move,**

The Omni should be able to rotate and move each of its wheel motors and be able to move its body and change position, otherwise it will not be considering an Omni robot and thus it will not satisfy the main criteria.

- **The Omni Robot must be able to change direction without rotating,**

To be an Omni robot, the robot must be able to use its wheels to move in any direction without the need of rotating its base. Since the wheels are constructed in such way that they could move in any direction without the need of rotating the base. This is the major advantage of the Omni wheels.

- **The Omni Robot can be controlled using a remote,**

Total ability to control the robot and to be able to provide instruction and input to it was an essential part of this robot design. To do this a remote control was use to allow the robot to move. It has been the scope of this thesis to prove that a robot with largest arms can interact with object that are at higher places it consider out of scope to program any autonomous behaviour that would allow the robot to interact without human interaction.

- **The Omni Robot must be able to move/use arms,**

One of the main goals of this project is to prove that the Omni robot can use the arms to interact with objects. To be able to move or use arms is one of the core requirements.

- **The Omni Robot must be able to interact with object at high places,**

This is the main goal of this research by higher we define objects that are on a small table less than 1m in height.

- **The Omni Robot must be able to rotate Hands,**

The robot should be able to rotate the arms this will prove that a large grip can be used successfully without any disadvantage.

- **The Omni Robot must be able to rotate base,**

While Omni wheels can cover any direction (Forward, backward, right, and left) to grant additional mobility, the base should be able to rotate and to have a 360-degree freedom.

1.4.2. Non-Functional Requirements

- **The Omni Robot must be stable,**

The base should be stable to hold a large arm, without tripping over.

- **The Omni Robot must be relatively fast,**

The robot should have enough speed and be able to use its arms at a good speed.

- **The Omni Robot must have Accurate Positioning,** The robot should be able to follow the remote controller's input instruction in an accurate range and allow as much control for the user as possible.

- **The Omni Robot must be Robust,**

All the robot wiring should be covered and protected, to make the robot more robust. This will also make the robot moving friendly, since the wiring and its vital parts will be covered and concealed.

1.5. Related Work

Some of the latest advancement in autonomous robots is detailed in ref. [3], several robots have been viewed. Most of them are out of scope of hobbies or researchers and their used in everyday situation or they called upon to address a disaster can be divide the latest advancements in robot technology into these categories, Navigation, Motion, Power Management, Safety and communication.

1.5.1. Navigation

Today for guidance, robots use Dual GPS receivers, which allow them to determine their position and guide them to their waypoints. Wheel track this means that by knowing how much a wheel had rotated the operator of the robot can approximately calculate and pinpoint where the robot has gone. Lidar is a system that can calculate distance-using laser. Lidar can also be used to identify anomalies on the terrain. Radars can be used to determine where other objects are, even if they are hidden. Ultrasonic can be used for close or long range distance. 3-Axis Gyroscope this will work as a compass to any robot. 3-Axis accelerometer this will help the robot to understand how fast its movement is when it is combined with a magnetometer and finally cameras.

1.5.2. Motion

While the motors and servos exist for several years they have not undergone major technological advancements. Several advancements exist in monitoring and the control of the motor. The precise movement of the motor is necessary for controlling the position of the robot. According to [3,4] MCU is a motor control application that has mixed-signals capabilities that can accurately control, Stepper motors DC Motors , AC Motors. The MCU can report RPM (Revolutions per minute) of a motor, status, motor temperature, and motor voltage. This can provide an insights regarding the motor's position, motor's health and even how slippery is the surface that the robot is on.

1.5.3. Power management

The power supply has seen minor or no advancements in recent years. Most of the robots are using battery systems except for few that are using fuel power engines. While almost no advancement exists on power management except for larger batteries, a high advancement exists on power monitoring. Since the robot is capable to understand when the battery is, running low and give feedback back to humans.

1.5.4. Safety

Safety is the protection of the robot from humans and other danger that may exists in the environment. Classical approaches are still employed, for example, from ref. [3] an ultrasonic ring is suggested. This ring will ensure that no object will go near the robot without alerting the controller.

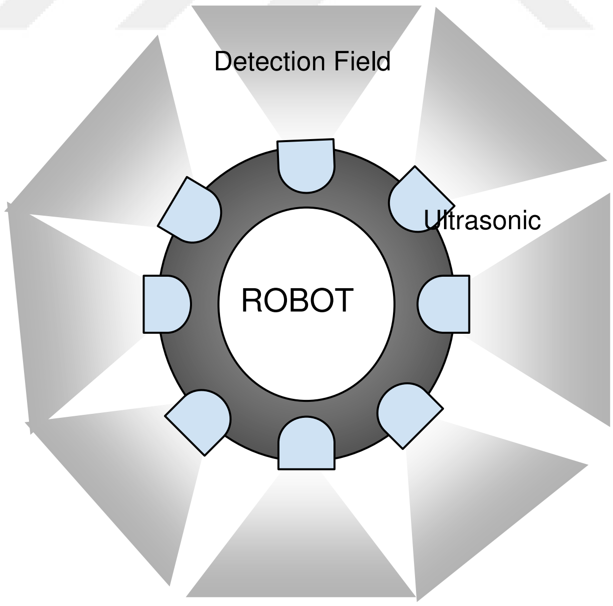

Figure 1.2 Ultrasonic Ring.

Figure 1.2 shows the robot using Ultrasonic. An ultrasonic ring consists of several ultrasonic sensors attached next to each other. When an object gets into their range, they alert the controller. Another set of sensors that have been used are light sensors to detect if terrain exist.

1.5.5. Communication

Communication is the ability of the robot to send signals to a designate system and receive new commands from it. The most common ways of communication are the Bluetooth for short-range not industrial models and Wi-Fi for industrial standard models. Although the review of the advancement is necessary is it very important to view some of the application of such advancement. The first robot that was reviewed has dumb body as a figure 1.3 this robot has a simple design .It consist of a metallic body that has six wheels .This model is very stable, and it can carry a substantial weight. Additionally, it can navigate from one point to another and unload the materials. It is ideal for construction sites.

Figure 1.3 Dump Truck.

This robot us a figure 1.4 can move in every direction by steering its wheels like a car. Thus grants some mobility, but it cannot change direction instantly unlike the robot in this thesis It is also been used in construction sites, it has a griper that can catch material and load it into the track. It can move to the designated location and unload the track. For maximum stability, this model is again equipped with six wheels; the robot steers by setting one set of motors to forward and the other one to go backward. This allows the robot to steer almost in place. This model has a single arm that allows it to operate in a single place at a time, the robot designed in this thesis, on the other hand has two arms that allow it to interact with object all around it.

Figure 1.4 Debris Remover.

This robot is also been used in construction sites, it has a griper that can catch material and load it into the track. Then it can move to the designated location and unload the track. For maximum stability, this model is again equipped with six wheels; the robot steers by setting one set of motors to forward and the other one to go backward. This allow the robot to steer almost in place. This model has a single arm that allows it to operate in a single place at a time, the robot designed in this thesis, on the other hand, has two arms that allow it to interact with object all around it.

Figure 1.5 The Disaster Search and Rescue Omni-chassis.

This robot in figure 1.5 is used for search and rescue mission. This robot has a set of cameras that can detect danger to human life. It can operate using the two arms to pull out humans out of difficult situations. The arms are multifunctional and can be equipped with several different tools that can be used depending on the occasion. This robot is the cutting edge of the autonomous robots. While this robot has many impressive features, it is still limited by its size.

1.6. Outline of the thesis

In the following chapter (Chapter Two) the mechanics of the Robot movement will be explained using kinematic controls. The chapter will further explain the meaning of forward kinematics and how this could be used to directly control the motors. The chapter will also explain inverse kinematic and the algorithm that are using to control the motor to reach the desire point. Thereafter, at Chapter 3, the construction of the Robot will be examined in details, giving ample explanation of each part of the Robot and the way these parts were manufactured and Chapter 4 will explain how the wirings were installed, the power supply that was used and finally the remote control. In the same chapter details, regarding the Arduino and the code that were developed will be explained to make the robot functional. In Chapter 5, the advantages and the disadvantages of the current Omni Robot design will be discussed. Finally, at Chapter 6 a discussion of the results and assumptions that can be derived from this thesis will be demonstrated. Also, detailing the scope for improvements and future work.

2. MODELLING OF MOBILA MANIPLATOR

2.1. Kinematic

Classical mechanics contains a branch that known as kinematic. Kinematics is the description for the motion of rigid bodies, their movement and who how they can reach specific points. Kinematics considered to be motion geometry. Unlike physics, the kinematic frequently ignore the forces that are used to move the object. For this reason, kinematics is use in various fields of studies like astrophysics, where the forces are mostly unknown, mechanical engineering, robotics and biomechanics where the forces derive from a well-known source and they are mostly irrelevant to the goals of the research or study. While kinematics does not consider the source force, they consider the velocity of the subject object. For example, kinematic solutions are considering Geometry of an object, velocity, acceleration of the various point/joints in our system. This makes them ideal to move a hand, since such studies can consider multiple joints and extend them, rotate, move them to reach a specific point. Additional by subdividing the problem into sub problems we can have finger touching specific part of the object and having remote manipulation. Such movements are called kinematics analysis, and they can synthesize a set of movements that can assist in robotics. The system of kinematics can dynamically receive new input and try to recalculate to reach a specific point. Additional kinematic systems consider external motion for example if we attach a hand to a human, the human can still use his arm to move. The movement of the arm is an external movement that changes the position of the current joints. Apart from robotics similar theories are been applied to computer animations, where the kinematics are heavily used to move animated character around a scene or a level. This is making a robot compatible to be represented and even receive motion from a 3D Space application. Such application can manipulate several thinks expect the robot. They are two types of kinematics that are been used in robotics the forward kinematics and the reverse kinematics. It is of those can be used for different occasions and can adapt to the locomotion technique that could be used. In this thesis, the forward kinematics was chosen.

2.2. Kinematic Control

Kinematic Control is using the theory of geometry to assist a robot joints to reach a specific or generic target. This differs from the usual DC movement approach, where the control of the motors is limited. By using kinematic controls, one could have a more precise control of the motors and the servos. For example instead of commanding the control to allow power to pass though the servo and expect the servo to work, one would command the servo to rotate 30 degrees. This allows the use of simple or complex geometry rules that will grant this new robot design a higher level of precision. While kinematic can be used to move the robot, for example on the wheels they are far more useful when they are used on arms. Since for a mechanic arm to catch an object or interact with an object it would need absolute precisions. The movement using degrees can offer such precision. Additionally, such accuracy can allow the robot to move several motors at the same time, for example, a chain of motors. For this reason, kinematics it is often used to control set of joints or human like bones and arms. Kinematics allows the use of motion geometry in the robots.

2.3. Forward kinematic

In this said, that a robot is using forward kinematics when the controller is directly commanding the motors. For example, by sending a command Motor 'A' rotate 30 degrees.

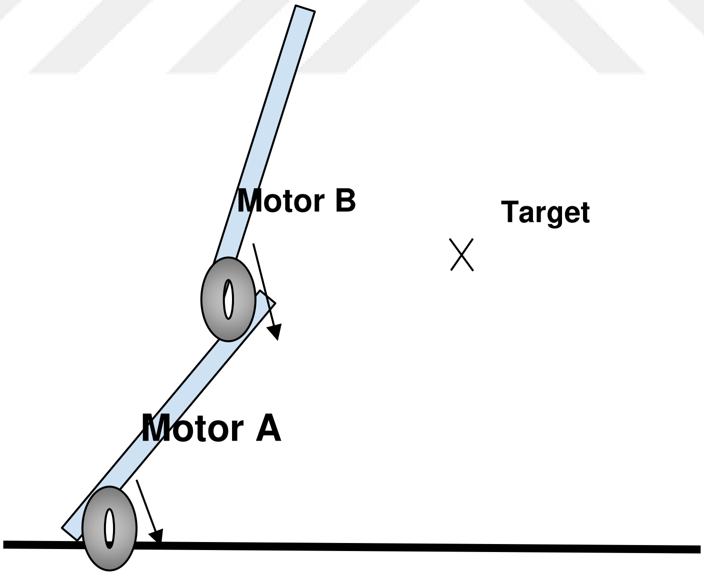

Figure 2.1 Forward Kinematics.

Such approach is straightforward and is been used in many cases. Forward kinematics are being used for moving a robot around using wheels. Forward kinematics can be modified by control algorithm such as PID controller to help the robot reach the desired position. Additionally, a filter can be employed to further help the robot navigate through the environment. Such kinematics is giving better control to the user since it can be easily monitored. Forward kinematics is heavily dependent on the correct pre-calculation and in pre-defined movement. While this approach is simple, and it covers many needs, it has some major drawbacks. For example, it is almost impossible or very difficult to use a gripper using forward kinematics. Since one must animate it of its joins manually and by approximation. On the other hand, inverse kinematic is ideal for such think. figure 2.1 shows the use of Motor ‘A’ and Motor ‘B’ to reach target, in this case a direct command is sent to Motor ‘A’ to rotate 30 degree and to Motor ‘B’ to rotate 90 degree. The system has no information regarding the target. Forward kinematics of a robot that has DOF it represented us below.

$$ {}^{base}_{end-effector}T = {}^{0}_{1}T\,{}^{1}_{2}T \ldots {}^{n-1}_{n}T \qquad (2.1) $$

2.4. Inverse kinematic

The Inverse kinematic approach is the opposite of forward kinematics in this case one knows where the target is, and the controller modify the joints to reach that target. This is ideal for grabbing objects, or having a camera monitoring a specific place. In the first case, the gripper will reach and try to grab the object.

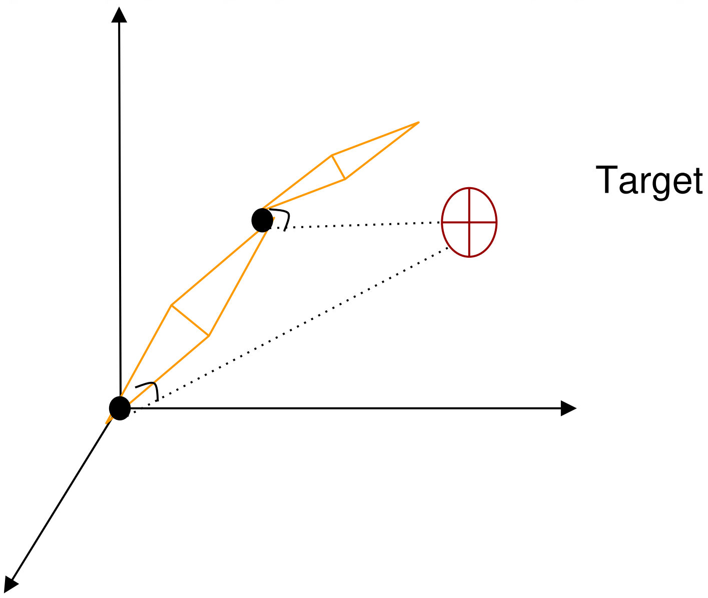

Figure 2.2 Reverse Kinematics.

In the second case, the arm that has the camera will try its best to reach the target. This way the camera will be turned into the right direction. Another use of the inverse kinematic is walking, since the terrain changes the foot need to be able to follow the different terrain height (contour). Figur 2.2 shows, Reverse kinematics tries to recalculate and remap angle “a” and angle “ b” to reach the target. If “a” and” b” both rotate the target will be reached.The transformation matrix it divided in to 3 regions. The first 3x3 sub-matrix from $T_{1,1}$ to $T_{3,3}$ represents unit-vector of resulting transformation. Elements from $T_{1,4}$ to $T_{3,4}$ defines x, y and z coordinates of the resulting frame based on the reference coordinate system that placed on base element. $T_{4,4}$ Is scaling factor, and other elements are zero. Thus, the transformation matrix written as given below.

$$ {}^{base}_{end-effector}T = \begin{bmatrix} r_{11} & r_{12} & r_{13} & p_x \\ r_{21} & r_{22} & r_{23} & p_y \\ r_{31} & r_{32} & r_{33} & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2.2} $$

2.5. Differential kinematic

A problem that often appears in the inverse kinematic is that the target can be mobile. This requires a recalculation of the joints to help them match the new target. Differential kinematics can offer a solution to this problem since they consider the velocity of the target and the ending joint. To calculate the velocity of the last joint it is necessary to calculate the velocity of the multiple joints.

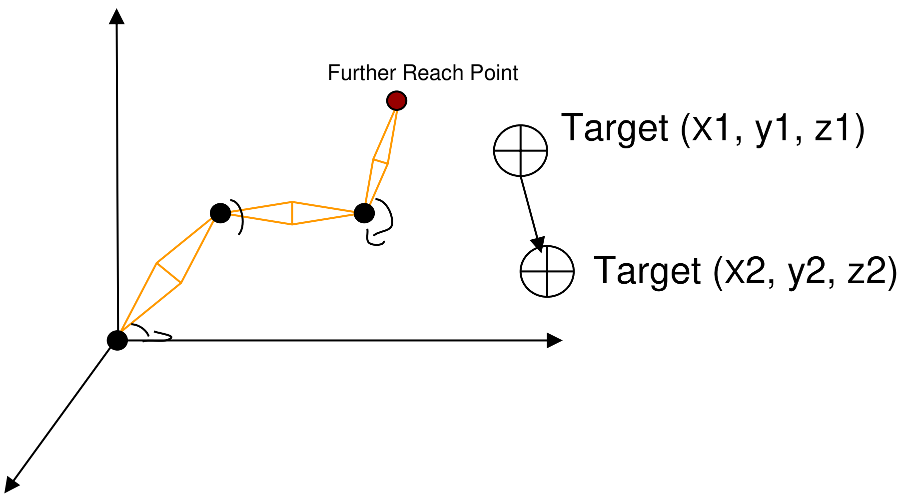

Figure 2.3 Differential kinematics.

In differential kinematics, many methods can be developed to achieve such results. More specifically, differential kinematics can coordinate chain of joints in multiple-joint robotic system such as ours. To find the correlation for our joints, we need to calculate the joint displacement and the target location and use them to solve the individual joint motions. These functions like the reverse kinematics. Figure 2.3 shows that the chain of joints is recalculating to reach the target.

2.6. Denavit-Hartenberg parameters and conversions matrices

D-H is the method that uses four parameters is the most common method for describing the robot kinematics. These parameters a_i-1, α_{i-1}, d_i and θ_i are the link length, link twist, link offset and joint angle, respectively. Coordinate frame is attached to each joint to determine DH parameters. Figure 2.4 shows the coordinate frame assignment for a general manipulator.

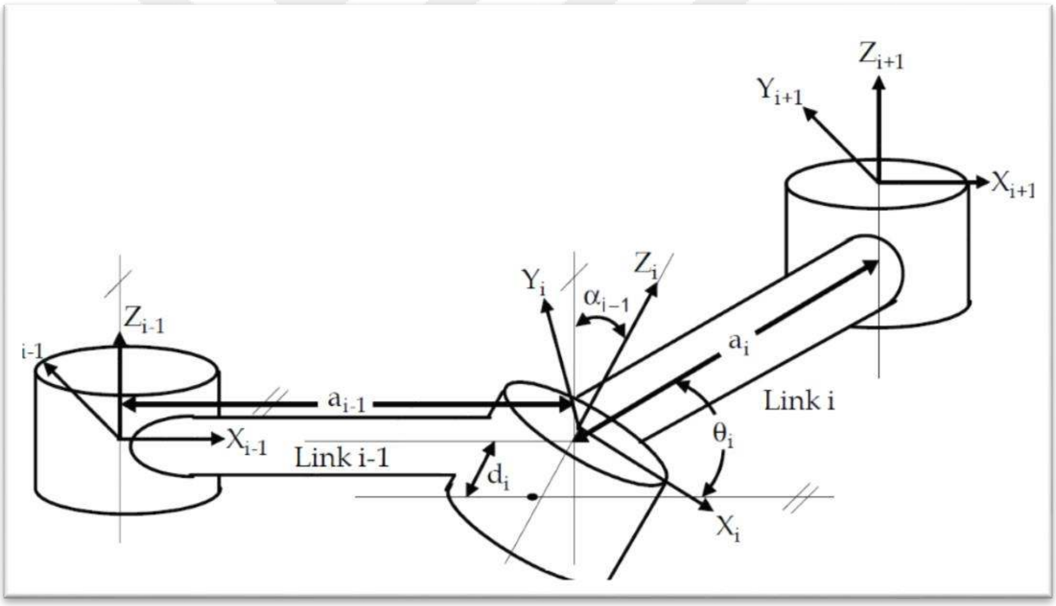

Figure 2.4 Coordinate frame assignment for a general manipulator.

As shown in Figure 2.4, the distance from Zi-1 to Zi measured along Xi-1 it assigned as ai-1, the angle between Zi-1 and Zi measured along Xi assigned as αi-1, the distance from Xi-1 to Xi measured along Zi is assigned as di and the angle between Xi-1 to Xi measured about Zi is assigned as θi. The general transformation matrix ${}^{i-1}_{i}T$ for a single link can obtained as follows

$$ {}^{i-1}_{i}T = R_x\,(\alpha_{i-1}) D_x(\mathrm{a}_{i-1}) R_z\,(\theta_i) Q_i(\mathrm{d}_i) \tag{2.3} $$

$$ {}^{i-1}_{i}T(q) = \begin{bmatrix} C\theta_i & -S\theta_i\, C\alpha_i & S\theta_i\, S\alpha_i & a_i\, C\theta_i \\ S\theta_i & C\theta_i\, C\alpha_i & -C\theta_i\, S\alpha_i & a_i\, S\theta_i \\ 0 & S\alpha_i & C\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2.4} $$

Where

R_x and R_z present rotation, D_x and Q_i denote translation, and $c\theta_i$ and $s\theta_i$ are the short hands of $\cos\theta_i$ and $\sin\theta_i$, respectively. The forward kinematics of the end-effector with respect to the base frame is determined by multiplying all of the ${}^{i-1}_{i}T$ matrices.

$$ {}^{basei}_{end-effector}T = {}^{0}_{1}T\, {}^{0}_{i1}T \dots\dots\dots .\, {}^{n-1}_{n}T \tag{2.5} $$

An alternative representation of ${}^{basei}_{end-effector}T$ can be written as

$$ {}^{0}_{8}T = \begin{bmatrix} n_x & o_x & a_x & P_x \\ n_y & o_y & a_y & P_y \\ n_z & o_z & a_z & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2.6} $$

Where T represent the rotational elements of transformation matrix (k and j=1, 2 and 3). p_x, p_y and p_z denote the elements of the position vector. For a six jointed manipulator, the position and orientation of the end-effector with respect to the base is given by

$$ {}^{0}_{8}T = {}^{0}_{1}T * {}^{1}_{2}T * {}^{2}_{3}T * {}^{3}_{4}T * {}^{4}_{5}T * {}^{5}_{6}T * {}^{6}_{7}T * {}^{7}_{8}T \tag{2.7} $$

2.7. Mobile Robot Kinematics (MRK)

Since the designed robot is a hybrid with a serial manipulator on a mobile robot, mobile robot kinematics have to generate.

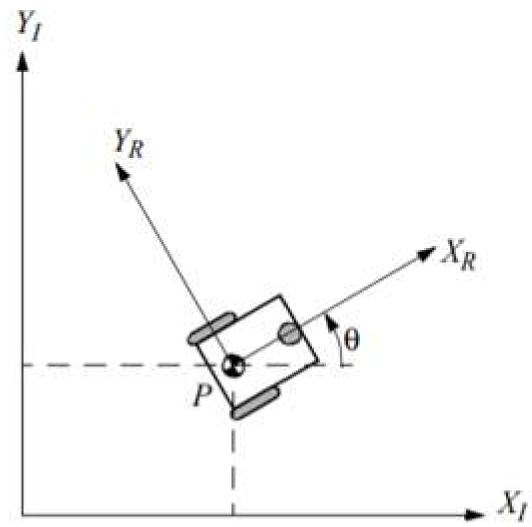

Figure 2.5 Mobile Robot Kinematics (MRK).

As a figure can see in MRK figure: 2.5 a relationship between the local reference frame of the robot and the global reference frame have to obtain.

Point P is the reference point on the robot according to global reference frame. Position and the orientation of the robot can be defined by (x , y) and (θ).

$$\zeta = \begin{bmatrix} x \\ y \\ \theta \end{bmatrix} \tag{2.8}$$

There is also need for a rotation matric, in order to mapping local coordinates to global reference frame.

$$R(\theta) = \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{2.9}$$

Thus, motion in global reference frame it can mapped into local reference frame as

$$\zeta_R = R(\theta)\zeta \tag{2.10}$$

If velocity in the global coordinate system is given, motion respected to robot's local axes can calculated.

2.8. Calculate of forward kinematics by D-H parameters

The individual equations for each element in terms of the joint angles are given in the appendix in addition to MATLAB code that can be used to compute the result for a given set of angles. As can be seen by the resulting equations, the kinematic solution will be difficult to achieve. A closed form solution for a simple six DOF robot such as this does exist, but in general, the solution must be achieved numerically. This was implemented using Specially with Matlab, in this research describes it very clearly that relation between Kinematic with controlling by Matlab software. To complete this process. Firstly should be identified the project axis as shown in figure 2.6 and determine the dimensions between joints and find matrices for each arm separately.

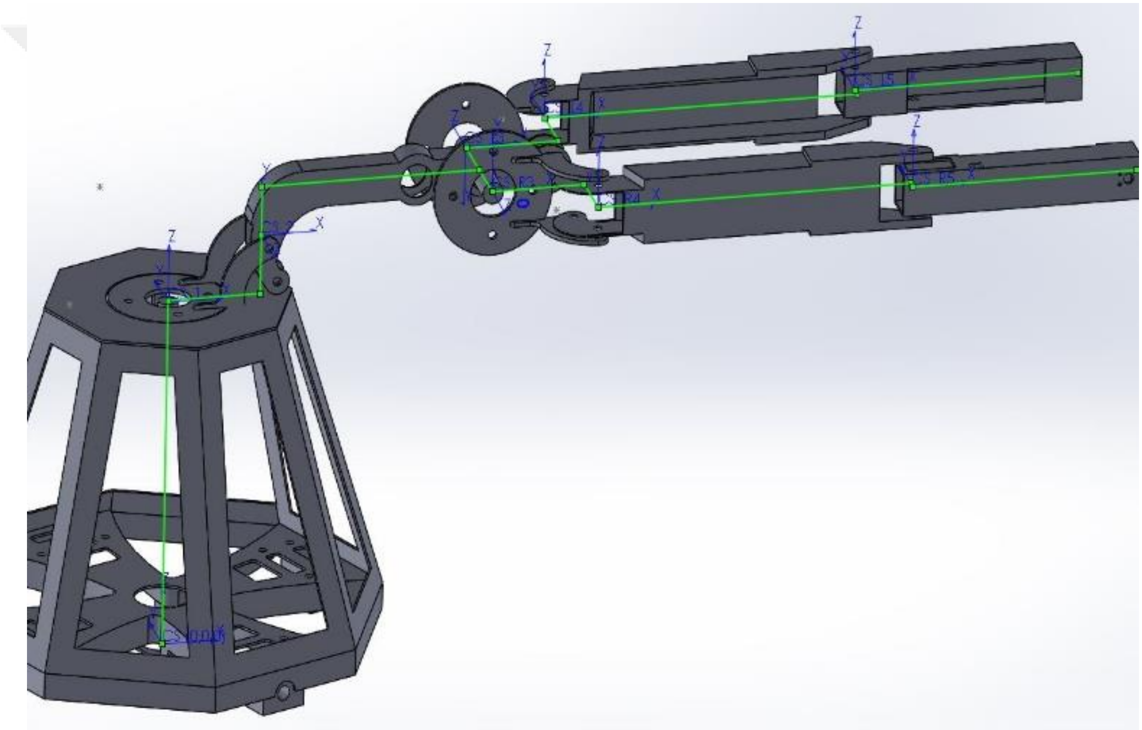

Figure 2.6 Shows rotation axis at zero position.

L_1	=	401	L_7	=	113.57
L_2	=	113.57	L_8	=	70
L_3	=	70	L_9	=	55
L_4	=	57.46	L_{10}	=	383.95
L_5	=	266.98	L_{11}	=	258.75
L_6	=	66.5			

Table 2.1 and 2.2 shows the D-H parameters obtained from the configuration of the mechanical design and frames given figure 2.6.

Table 2.1. D-H-Trans-Matrix of Right Arm

	α I-1	ai-1	di	θ i
1	0	0	L_1	0
2	+90	L_2	L_3	θ_1
3	-90	0	0	θ_2
4	+90	L_5	L_4	0
5	0	0	L_6	0
6	-90	L_{7+L9}	L_8	θ_3
7	0	L_{10}	0	θ_4
8	0	L_{11}	0	θ_5

Table 2.2. D-H Trans-Matrix of Left Arm

	α I-1	ai-1	di	θ i
1	0	0	L_1	0
2	+90	L_2	L_3	θ_1
3	-90	0	0	θ_2
4	+90	L_5	L_4	0
5	0	0	L_6	0
6	-90	L_{7+L9}	L_8	θ_3
7	0	L_{10}	0	θ_4
8	0	L_{11}	0	θ_5

Classic D-H Trans-Matrix

$$ {}^{i-1}_{\ \ i}T(q) = \begin{bmatrix} C\theta_i & -S\theta_i\, C\alpha_i & S\theta_i\, S\alpha_i & a_i\, C\theta_i \\ S\theta_i & C\theta_i\, C\alpha_i & -C\theta_i\, S\alpha_i & a_i\, S\theta_i \\ 0 & S\alpha_i & C\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2.11} $$

Left Arm

$$ {}^0_1T = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & L_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2.12} $$

$$ {}^1_2T = \begin{bmatrix} C\theta_1 & 0 & S\theta_1 & L_2 * C\theta_1 \\ S\theta_1 & 0 & -C\theta_1 & L_2 * S\theta_1 \\ 0 & 1 & 0 & l_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2.13} $$

$$
{}^{2}_{3}T = \begin{bmatrix} C\theta_2 & 0 & -S\theta_2 & 0 \\ S\theta_2 & 0 & C\theta_2 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2.14}
$$

$$
{}^{3}_{4}T = \begin{bmatrix} 1 & 0 & 0 & L_5 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & L_4 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2.15}
$$

$$
{}^{4}_{5}T = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & L_6 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2.16}
$$

$$
{}^{5}_{6}T = \begin{bmatrix} C\theta_3 & 0 & S\theta_3 & C\theta_3 * (L_7 + L_9) \\ S\theta_3 & 0 & -C\theta_3 & S\theta_3 * (L_7 + L_9) \\ 0 & 1 & 0 & L_8 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2.17}
$$

$$
{}^{6}_{7}T = \begin{bmatrix} C\theta_4 & -S\theta_4 & 0 & L_{10} * C\theta_4 \\ S\theta_3 & 0 & -C\theta_3 & L_{10} * S\theta_4 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2.18}
$$

$$
{}^{7}_{8}T = \begin{bmatrix} C\theta_5 & -S\theta_5 & 0 & L_{11} * C\theta_5 \\ S\theta_5 & C\theta_5 & 0 & L_{11} * S\theta_5 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2.19}
$$

Left Arm Total Matrix

$$ {}^{0}_{8}T = {}^{0}_{1}T * {}^{1}_{2}T * {}^{2}_{3}T * {}^{3}_{4}T * {}^{4}_{5}T * {}^{5}_{6}T * {}^{6}_{7}T * {}^{7}_{8}T \tag{2.20} $$

$$ = \begin{bmatrix} n_x & o_x & a_x & P_x \\ n_y & o_y & a_y & P_y \\ n_z & o_z & a_z & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2.21} $$

$$ \begin{aligned} P_x = {} & L_2 * C\theta_1 - L_6 * S\theta_1 - L_8 * S\theta_1 + L_{11} * C\theta_5 * (C\theta_4 * (C\theta_1 * \\ & S\theta_2 * S\theta_3 + C\theta_1 * C\theta_2 * C\theta_3) - S\theta_1 * S\theta_4) - L_{11} * S\theta_5 * \\ & (S\theta_4 * (C\theta_1 * S\theta_2 * S\theta_3 + C\theta_1 * C\theta_2 * C\theta_3) + C\theta_4 * S\theta_1) + \\ & L_{10} * C\theta_4 * (C\theta_1 * S\theta_2 * S\theta_3 + C\theta_1 * C\theta_2 * C\theta_3) + L_5 * C\theta_1 * \\ & C\theta_2 - L_4 * C\theta_1 * S\theta_2 - L_{10} * S\theta_1 * S\theta_4 + C\theta_1 * S\theta_2 * S\theta_3 * \\ & (L_7 + L_9) + C\theta_1 * C\theta_2 * C\theta_3 * (L_7 + L_9) \end{aligned} \tag{2.22} $$

$$ \begin{aligned} P_y = {} & L_6 * C\theta_1 + L_8 * C\theta_1 + L_2 * S\theta_1 + L_{11} * C\theta_5 * (C\theta_4 * (C\theta_2 * \\ & C\theta_3 * S\theta_1 + S\theta_1 * S\theta_2 * S\theta_3) + C\theta_1 * S\theta_4) + L_{11} * S\theta_5 * \\ & \big(C\theta_1 * C\theta_4 - S\theta_4 * (C\theta_2 * C\theta_3 * S\theta_1 + S\theta_1 * S\theta_2 * \\ & S\theta_3)\big) + L_{10} * C\theta_4 * (C\theta_2 * C\theta_3 * S\theta_1 + S\theta_1 * S\theta_2 * \\ & S\theta_3) + L_5 * C\theta_2 * S\theta_1 + L_{10} * C\theta_1 * S\theta_4 - L_4 * S\theta_1 * \\ & S\theta_2 + S\theta_1 * S\theta_2 * S\theta_3 * (L_7 + L_9) + C\theta_2 * C\theta_3 * S\theta_1 * \\ & (L_7 + L_9) \end{aligned} \tag{2.23} $$

$$ \begin{aligned} P_Z = {} & L_1 + L_3 + L_4 * C\theta_2 + L_5 * S\theta_2 - C_2 * S\theta_3 * (L_7 + \\ & L_9) + C\theta_3 * S\theta_1 * (L_7 + L_9) - L_{10} * C\theta_4 * (C\theta_2 * \\ & S\theta_3 - C\theta_3 * S\theta_2) - L_{11} * C\theta_4 * C\theta_5 * (C\theta_2 * S\theta_3 - \\ & C\theta_3 * S\theta_2) + L_{11} * S\theta_4 * S\theta_5 * (C\theta_2 * S\theta_3 - C\theta_3 * \\ & S\theta_2) \end{aligned} \tag{2.24} $$

Right Arm

$$ {}_{1}^{0}T = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & L_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2.25} $$

$$ {}_{2}^{1}T = \begin{bmatrix} C\theta_1 & 0 & S\theta_1 & L_2 * C\theta_1 \\ S\theta_1 & 0 & -C\theta_1 & L_2 * S\theta_1 \\ 0 & 1 & 0 & l_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2.26} $$

$$ {}_{3}^{2}T = \begin{bmatrix} C\theta_2 & 0 & -S\theta_2 & 0 \\ S\theta_2 & 0 & C\theta_2 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2.27} $$

$$ {}_{4}^{3}T = \begin{bmatrix} 1 & 0 & 0 & L_5 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & L_4 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2.28} $$

$$ {}_{5}^{4}T = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & L_6 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2.29} $$

$$ {}_{6}^{5}T = \begin{bmatrix} C\theta_3 & 0 & -S\theta_3 & C\theta_3 * (L_7 + L_9) \\ S\theta_3 & 0 & C\theta_3 & S\theta_3 * (L_7 + L_9) \\ 0 & -1 & 0 & L_8 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2.30} $$

$$ {}_{7}^{6}T = \begin{bmatrix} C\theta_4 & -S\theta_4 & 0 & L_{10} * C\theta_4 \\ S\theta_3 & 0 & C\theta_3 & L_{10} * S\theta_4 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2.31} $$

$$ {}_{8}^{7}T = \begin{bmatrix} C\theta_5 & -S\theta_5 & 0 & L_{11} * C\theta_5 \\ S\theta_5 & C\theta_5 & 0 & L_{11} * S\theta_5 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2.33} $$

Right Arm Total Matrix

$$P_x = L_2 * C\theta_1 + L_6 * S\theta_1 + L_8 * S\theta_1 - L_{11} * C\theta_5 * (C\theta_4 * (C\theta_1 * S\theta_2 * S\theta_3 - C\theta_1 * C\theta_2 * C\theta_3) + S\theta_1 * S\theta_4) + L_{11} * S\theta_5 * (S\theta_4 * (C\theta_1 * S\theta_2 * S\theta_3 - C\theta_1 * C\theta_2 * C\theta_3) - C\theta_4 * S\theta_1) - L_{10} * C\theta_4 * (C\theta_1 * S\theta_2 * S\theta_3 - C\theta_1 * C\theta_2 * C\theta_3) + L_5 * C\theta_1 * C\theta_2 - L_4 * C\theta_1 * S\theta_2 - L_{10} * S\theta_1 * S\theta_4 - C\theta_1 * S\theta_2 * S\theta_3 * (L_7 + L_9) + C\theta_1 * C\theta_2 * C\theta_3 * (L_7 + L_9) \tag{2.34}$$

$$P_y\theta = L_2 * s\theta_1 - L_8 * C\theta_1 - L_6 * c\theta_1 + L_{11} * C\theta_5 * (C\theta_4 * (C\theta_2 * C\theta_3 * S\theta_1 - S\theta_1 * S\theta_2 * S\theta_3) + C\theta_1 * S\theta_4) + L_{11} * S\theta_5 * \left(C\theta_1 * C\theta_4 - S\theta_4 * (C\theta_2 * C\theta_3 * S\theta_1 - S\theta_1 * S\theta_2 * S\theta_3)\right) + L_{10} * C\theta_4 * (C\theta_2 * C\theta_3 * S\theta_1 - S\theta_1 * S\theta_2 * S\theta_3) + L_5 * C\theta_2 * S\theta_1 + L_{10} * C\theta_1 * S\theta_4 - L_4 * S\theta_1 * S\theta_2 - S\theta_1 * S\theta_2 * S\theta_3 * (L_7 + L_9) + C\theta_2 * C\theta_3 * S\theta_1 * (L_7 + L_9) \tag{2.35}$$

$$P_Z = L_1 + L_3 + L_4 * C\theta_2 + L_5 * S\theta_2 + C_2 * S\theta_3 * (L_7 + L_9) + C\theta_3 * S\theta_2 * (L_7 + L_9) + L_{10} * C\theta_4 * (C\theta_2 * S\theta_3 + C\theta_3 * S\theta_2) + L_{11} * C\theta_4 * C\theta_5 * (C\theta_2 * S\theta_3 + C\theta_3 * S\theta_2) - L_{11} * S\theta_4 * S\theta_5 * (C\theta_2 * S\theta_3 + C\theta_3 * S\theta_2) \tag{2.36}$$

figure 2.7 shows MATLAB blocks shape and figure 2.8 shows Window of SolidWorks assembly When examining the two forms, the first figure shows the application on the MATLB and the second form, the dimensions on the Solidwork , where the results of the numbers between the two programs are similar, therefore it can be say that MATLB applications are correct.

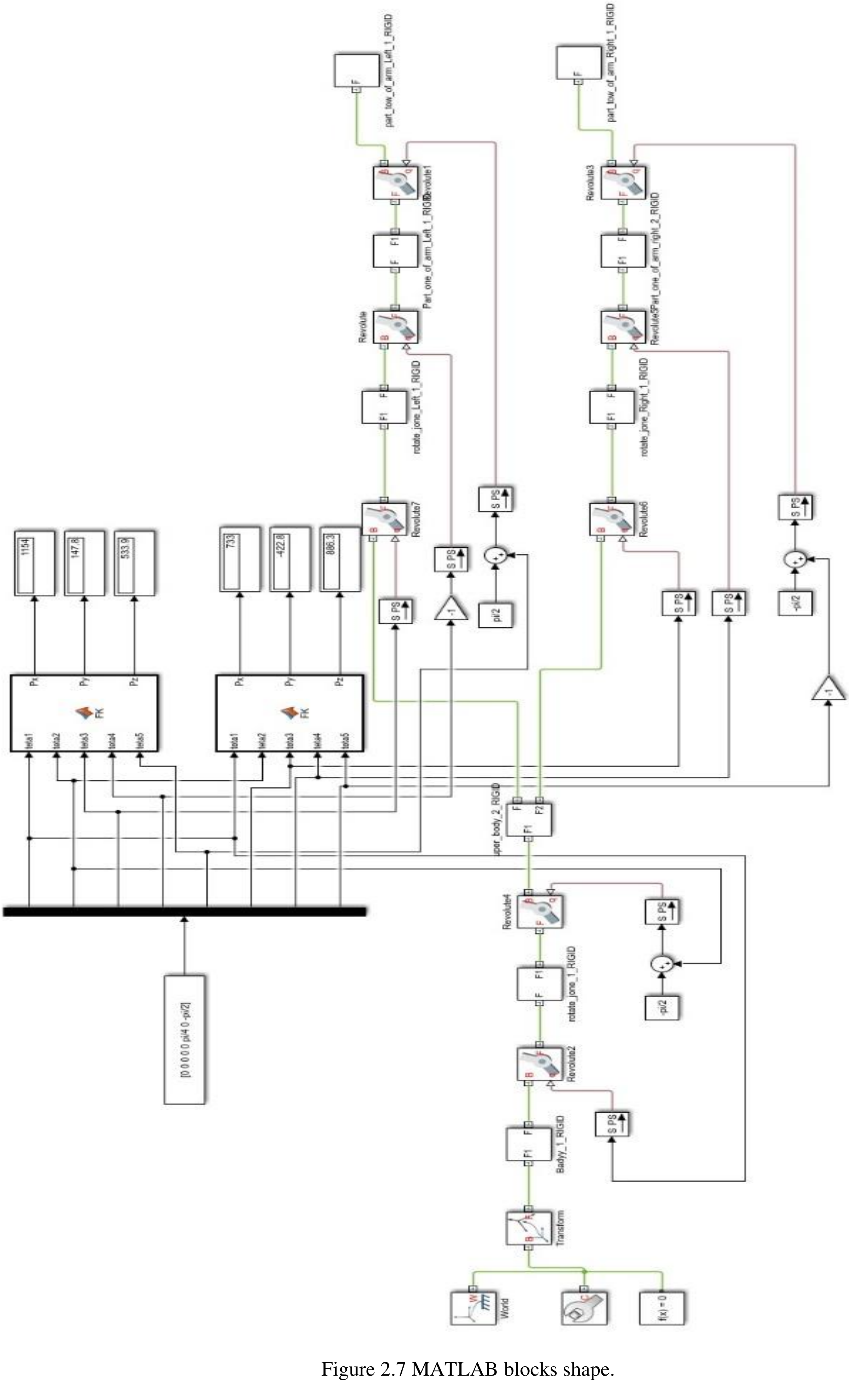

Figure 2.7 MATLAB blocks shape.

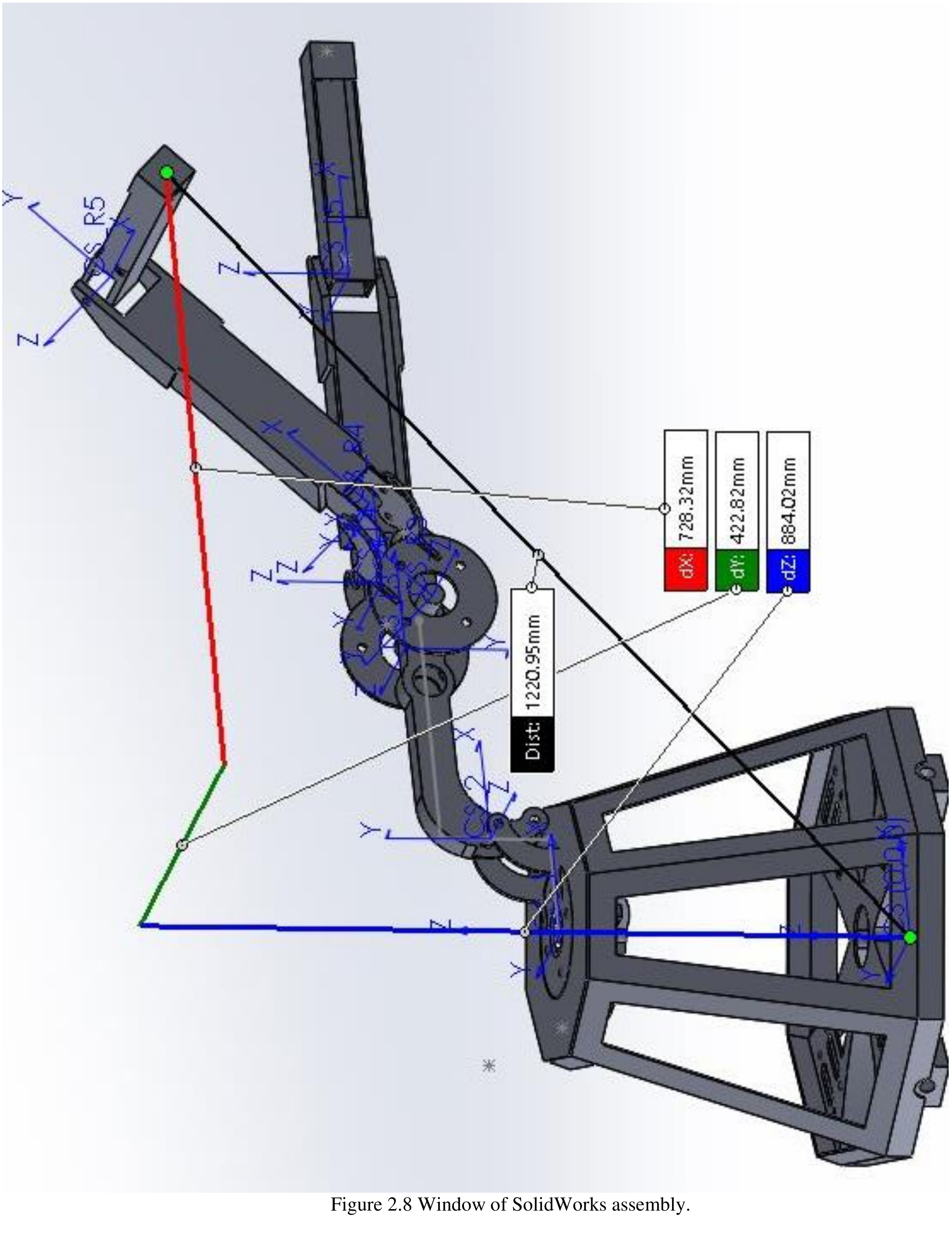

Figure 2.8 Window of SolidWorks assembly.

3. MECHANICAL DESIGN MODELS OF MANIPULATORS

Figure 3.1 shows the designed and completed omni robot.

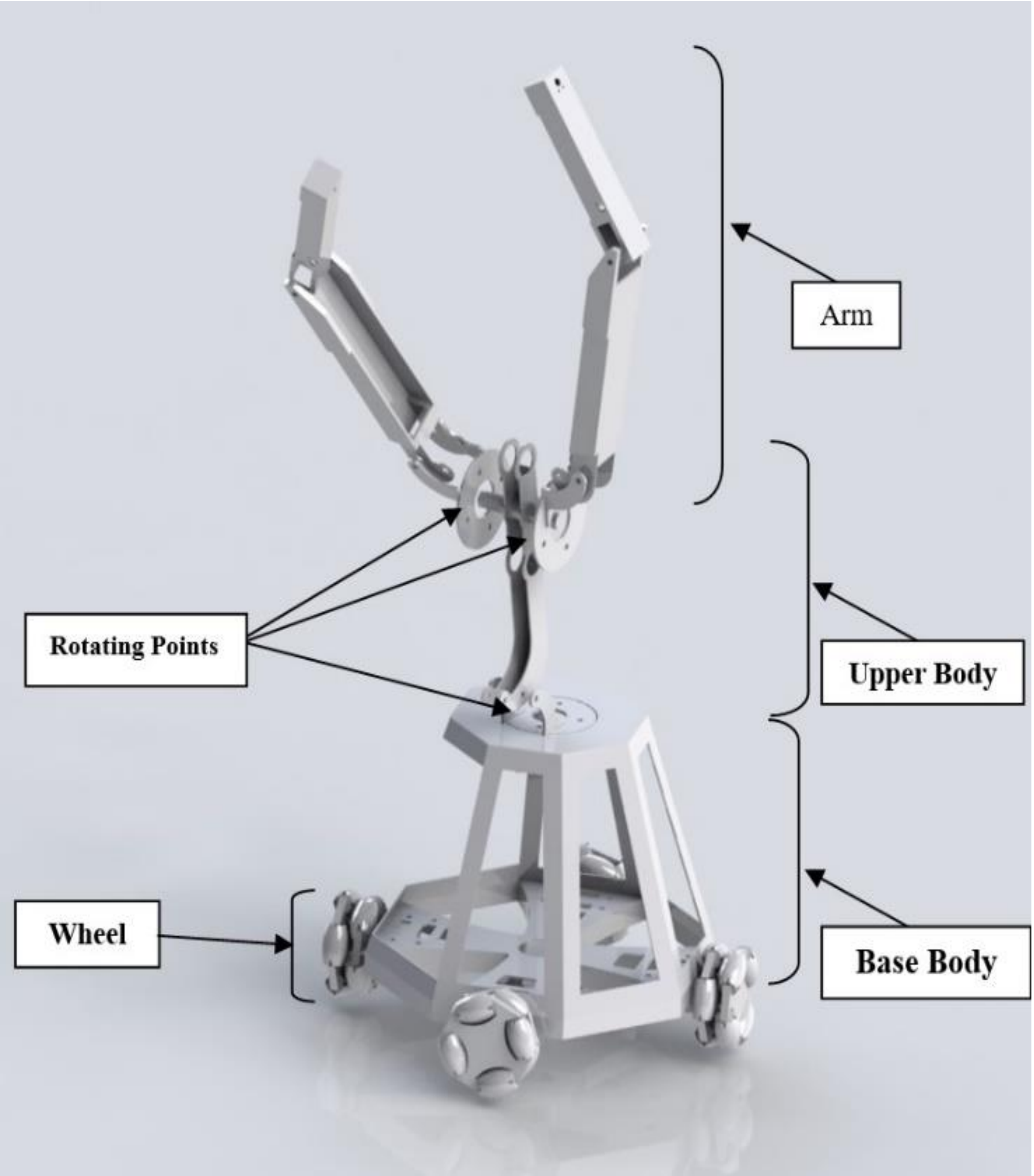

Figure 3.1 the robot is showing the main parts.

The figure 3.1 shows the main parts of this robot. In this chapter, each part of the robot will be explain in details together with the practical means of manufacturing these parts and the means of operating and controlling them.

3.1. The main parts

The robot consists of five main parts; these are -:

- **The wheels.**
- **The Lower Body.**
- **The Upper Body.**
- **The Rotating joints.**
- **The Arms.**

Each of these parts will be explain in the following paragraphs.

3.1.1. Wheels

The functions of the wheels were to enable the robot to move around in all directions as well as to rotate in 360^o degree around itself. The wheels were also responsible to carry the weight of the robot. This was a very complex and challenging task and it required a great deal of design and manufacturing skills. The design of the wheels is unique in the sense that it will allow the robot to move in straight line, as well as to rotate to any specific angle and to be able to rotate at 360^o. This movement should be achieved without causing the robot to lose any balance. There are four wheels in this robot, each wheel consist of two sub parts, the wheel itself and the motor that controls its movement. In each wheel there are eight plastic curved cylinders, these grouped and assembled in two units. Each of these units consists of four plastic curved cylinders housed and put together by specially designed steel (disks) plates and fixed by bolts and nuts. The two groups of these wheel/disk assembly were offset by 45^o and joined together to form an Omni wheel structure capable to carry out straight-line movement and rotation movements. The two grouped wheel/disk assembly where joined to the main body of the robot via a stainless steel shaft mounted by pillow block ball bearings and. The other end of the stainless steel shaft to connected the controlling motor. To visualize each of the components described above, the following figures shows these components:

1- The motor, as shown in the figure 3.2 each wheel group has ONE motor.

2- The base of motor, as shown in the figure 3.3 each wheel group has ONE base.

3- The stainless steel shaft 17mm with flange, as shown in the figure 3.4.

4- One central disk plate for the plastic curved wheel (group 1), as shown in the figure 3.5.

5- Two cover disk plates for the plastic curved wheels (group 1), as shown in the figure 3.6.

6- One central disk plate for the plastic curved wheel (group 2), as shown in the figure 3.7.

7- Two covers disk plates for the plastic curved wheels (group 2), as shown in the figure 3.8.

8- One Separate aluminium cylinder, as shown in the figure 3.9.

9- Stainless steel shaft 6mm (8 off), as shown in the figure 3.10.

10- Plastic curved cylinders (8 off), as shown in the figure 3.11.

12 - Two pillow block ball bearings, as shown in the figure 3.12.

13- One coupling as shown in the figure 3.13.

14- Eight Screws (10 mm* 10mm) for each wheel group.

15- Fur Screws (10 mm* 50mm) for each wheel group.

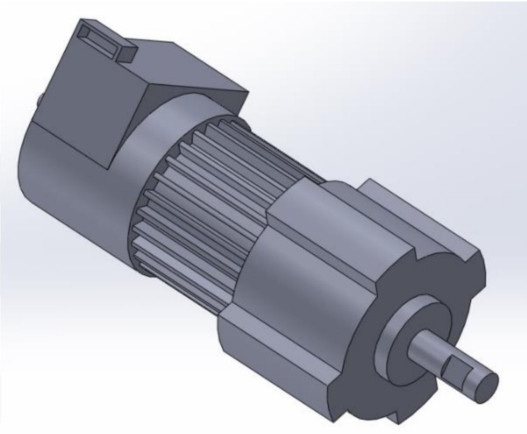

Figure 3.2 The Motor.

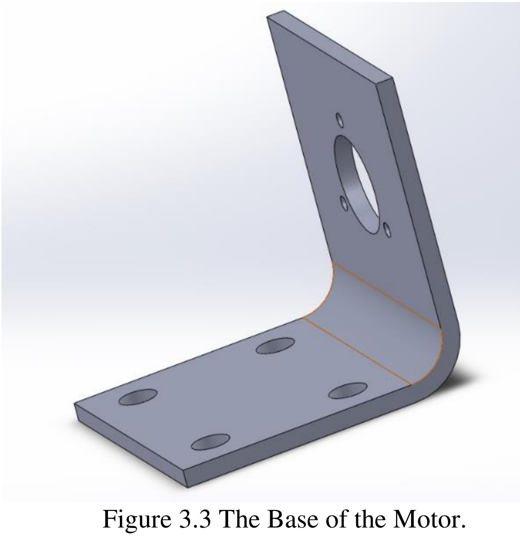

Figure 3.3 The Base of the Motor.

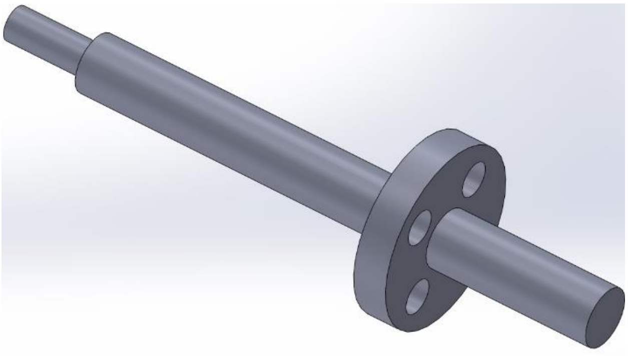

Figure 3.4 Stainless steel shaft with Flange.

Figure 3.5 The Central disk plate for the plastic curved wheel (group 1).

Figure 3.6 Two cover disk plates for the plastic curved wheels (group 1).

Figure 3.7 The Central disk plate for the plastic curved wheel (group 2).

Figure 3.8 Two cover disk plates for the plastic curved wheels (group 2).

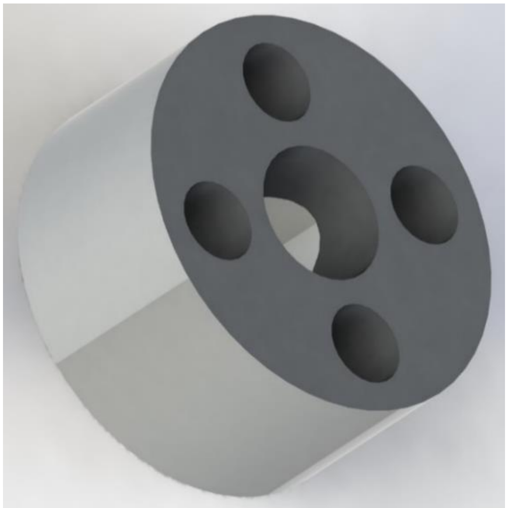

Figure 3.9 Separate aluminium cylinder.

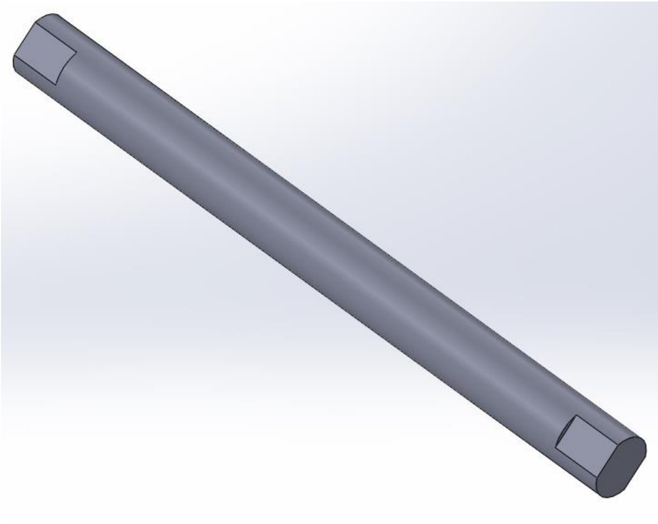

Figure 3.10 Stainless steel shaft 6mm.

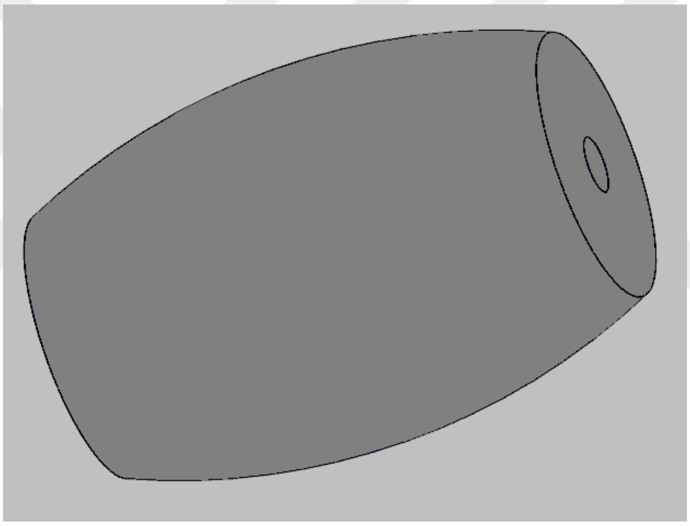

Figure 3.11 Plastic curved cylinders.

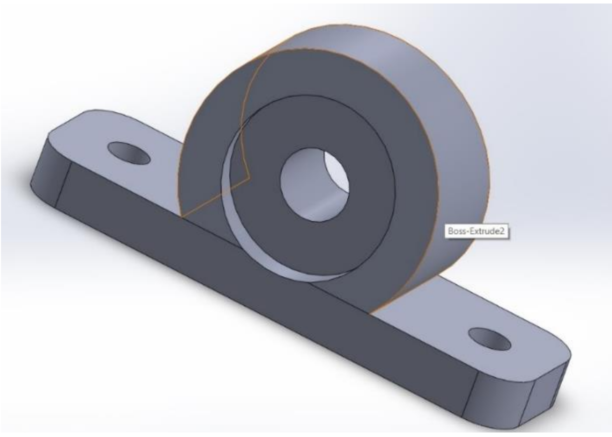

Figure 3.12 Pillow Block Ball Bearings.

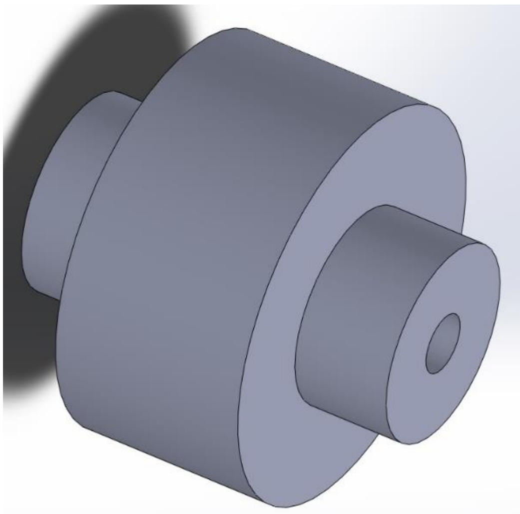

Figure 3.13 Coupling.

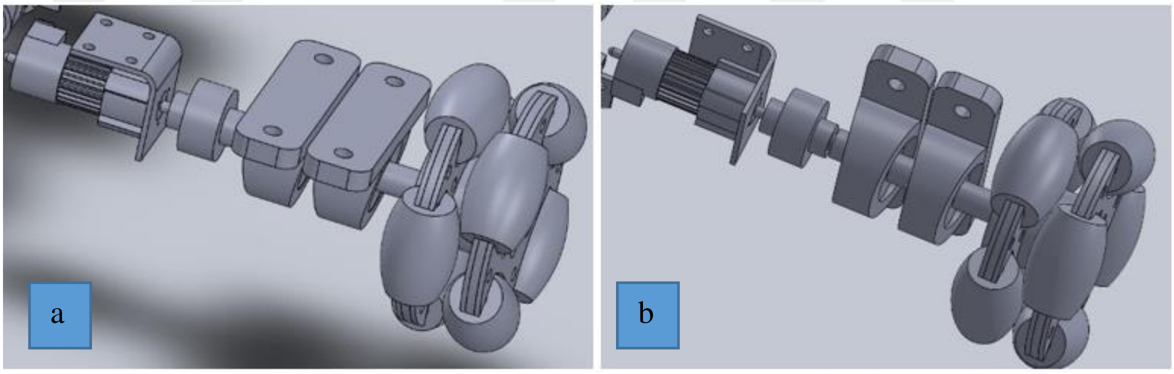

Figure 3.14 The assembly of wheel group of the robot as per our design.

Figure 3.14 a with b show two views for the wheel group final assembly. In this project, four wheel-groups assemblies needed. The following paragraphs shed light on the processes involved for achieving the manufacture of each these subparts of this wheel design.

- **The first step** in the making of the wheel was to manufacture the plastics curved cylinders. These were manufactured using standard Teflon Round stock. The Teflon stock was then machined using a Lathe machine to manufacture the precise shape of the curved cylinder. To achieve the latter a special round cutting tool was hand filed and hardened to enable the cutting of these curved cylinders. After the Teflon stock was rounded and curved using this special cutting tool the cylinder was then part cut from the round stock and a hole drilled through the cylinder for the steel shaft. Each Omni wheel require eight of these curved Teflon Cylinders, and since there are four wheels in the robot a total of 32 curved Teflon

Cylinders were manufactured. Figure 3.15 below show the various steps in the manufacturing of each of these curved Teflon Cylinders.

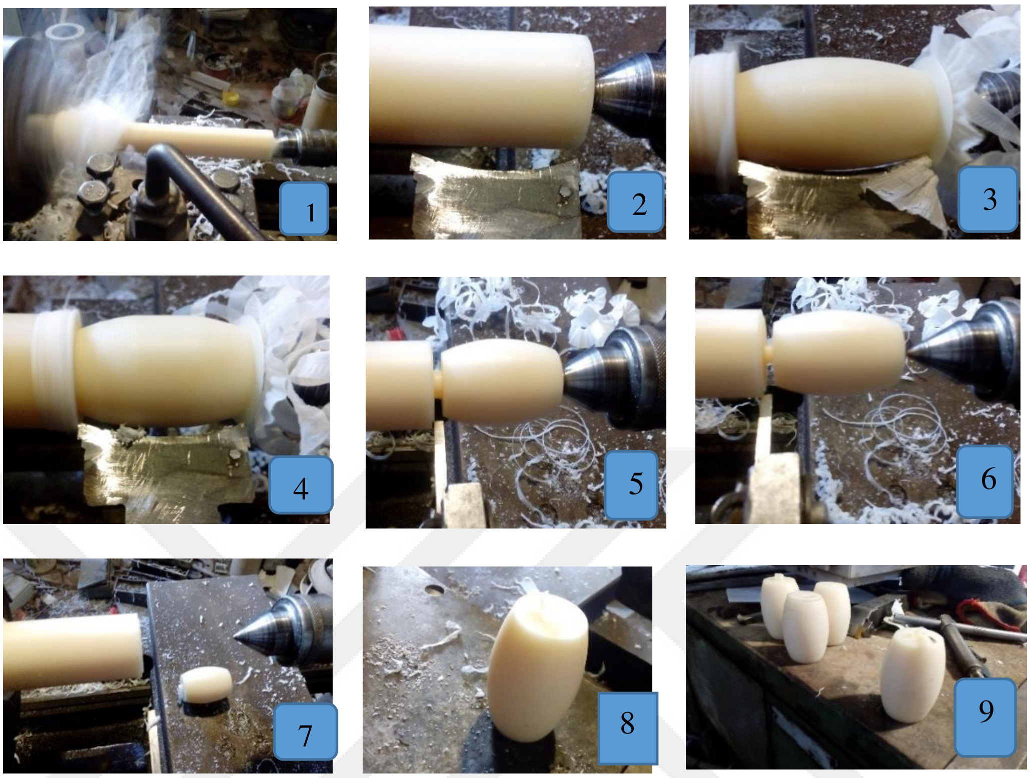

Figure 3.15 Carved Cylindrical plastic process.

- **The second step** in the making of these wheels was to insert the stainless steel shafts through the center axis of the curved cylindrical wheels. These shafts (6mm in diameter) were cut to size and the end was shaped for a free and easy rotational movement of the curved cylindrical wheels. Figure 3.16 below shows typical stainless steel shafts used for this purpose.

Figure 3.16 Stainless steel shaft.

- **The third step** in the making of these wheels once the stainless steel shafts were inserted through the curved cylindrical wheels was to secure these four wheels in position. This was achieved by sandwiching the curved cylindrical wheels/shafts into position by using three steel disks (3mm thickness). These disks were designed by AutoCAD and cut by CNC Plasma cutter. The three disks were consistent of one central steel disk with special notches to house the cylindrical steel shafts and two further steel disks to sandwich this central disks. The two disks were positioned one on the top of the central disk and one at the bottom. This sandwich was secured by bolts and nuts. The completed sandwich housing four cylindrical wheels is considered to be one group. Two of these groups are needed for each complete wheel group. The figure 3.17 shows these parts.

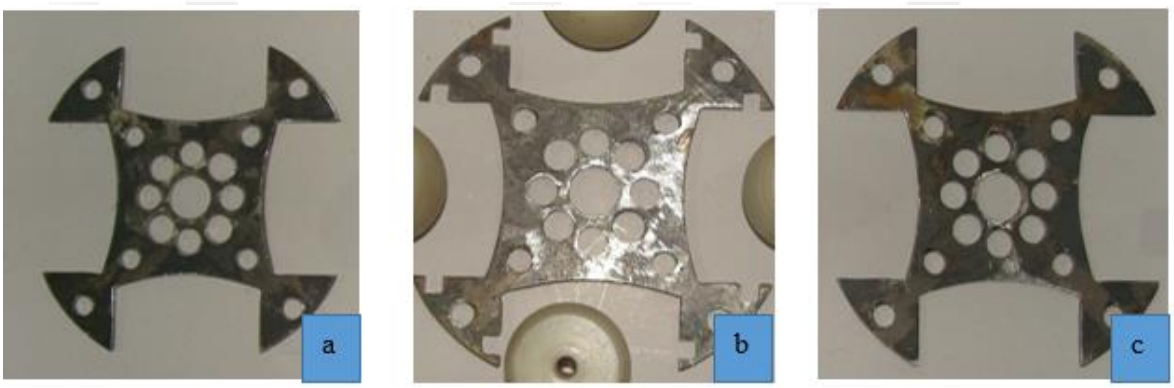

Figure 3.17 Central disk (b) and top and bottom disks (a and c) for group one of Omni Wheel structure.

The parts require for making one group of each of the Omni Wheels are shown in figure 3.18.

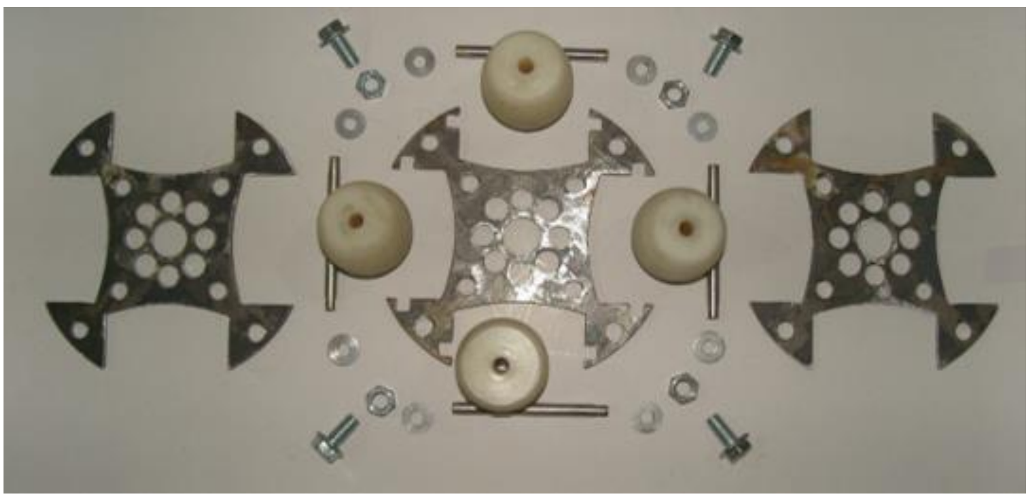
Figure 3.18 All parts needed to assemble group one of the Omni Wheel.

Figure 3.19 below shows the complete assembly of one group on the Omni Wheel structure. The figure shows the four cylindrical wheels with their central shafts all sandwiched and bolted together using the bolts and nuts.

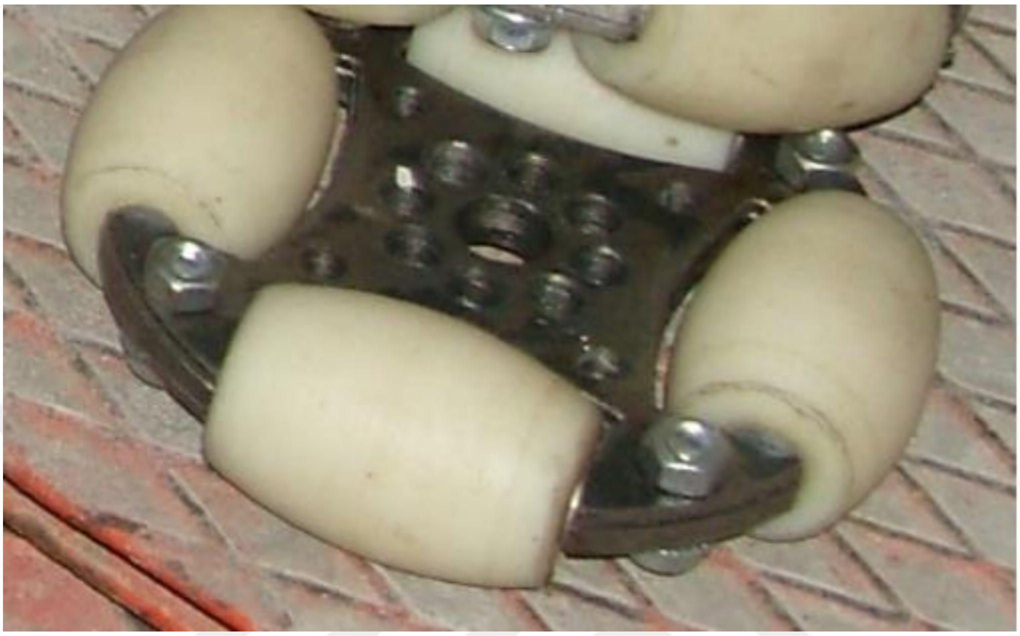

Figure 3.19 One group of Omni Wheel assembled.

Once the two groups of the Omni Wheels were completed, they were sandwiched together using separation part. Each group was offset by 45 degree to the other group. The separation part was made of Aluminum stock and show figure 3.20

Figure 3.20 Separate aluminium part.

Figures 3.21, 3.22 and 3.23 show the parts and the assembled second group on the Omni Wheel. It is worthwhile to mention that both groups have similar parts and means of assembly.

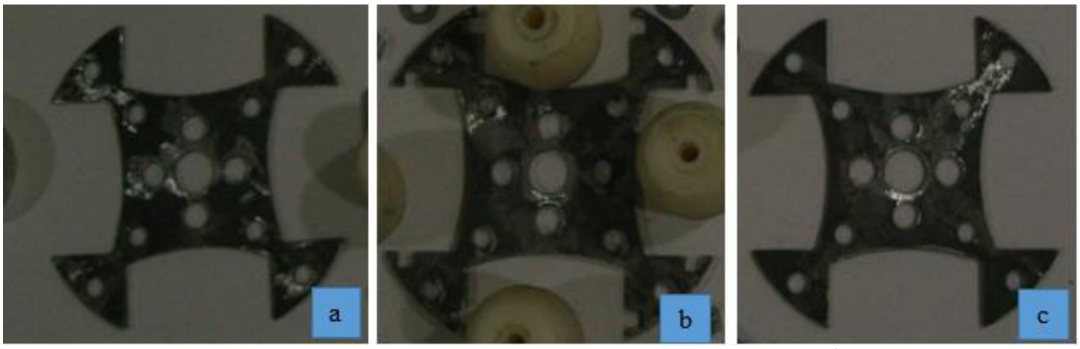

Figure 3.21 (b) Central disk and (a and C) top and bottom disks for the 2th group of Omni Wheel.

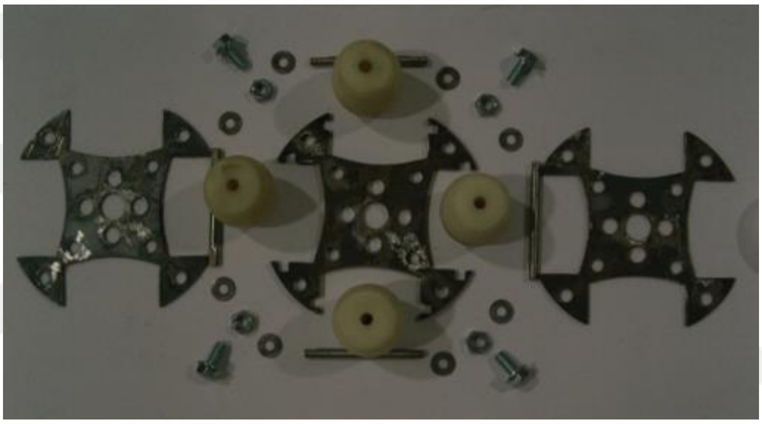

Figure 3.22 Shows all parts needed to assemble the group two of the Omni Wheel.

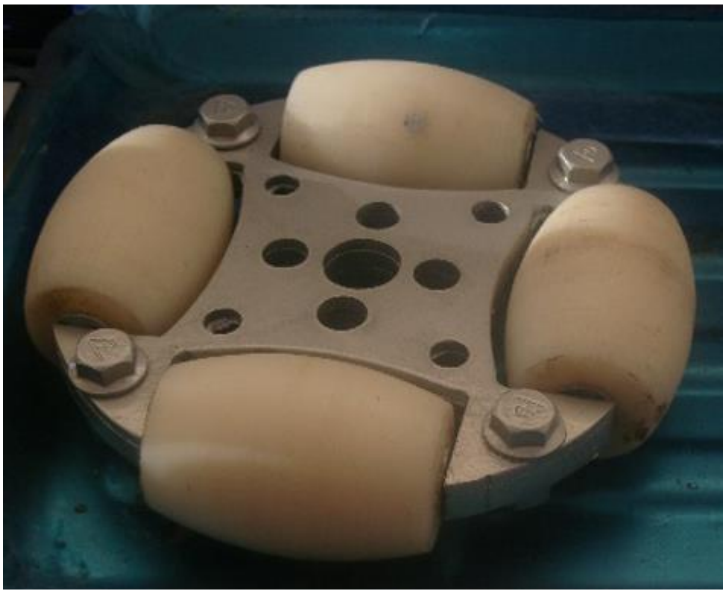

Figure 3.23 The group two of Omni Wheel assembled.

- **Step four** after completing wheel parts that can be manufactured a stainless steel shaft must linked with a flange to connect the wheels to motor and convert the movement to the wheels. Figure 3.24 show the shaft.

Figure 3.24 Stainless steel shaft with flange.

- **Step five** finally can be prepare the requirements that can buy to complete a single set of Omni wheel, which includes the following parts:

1. One Dc motor figure 3.25 (a).
2. Two bracket figure 3.25 (b).
3. One Coupling figure 3.25 (c).

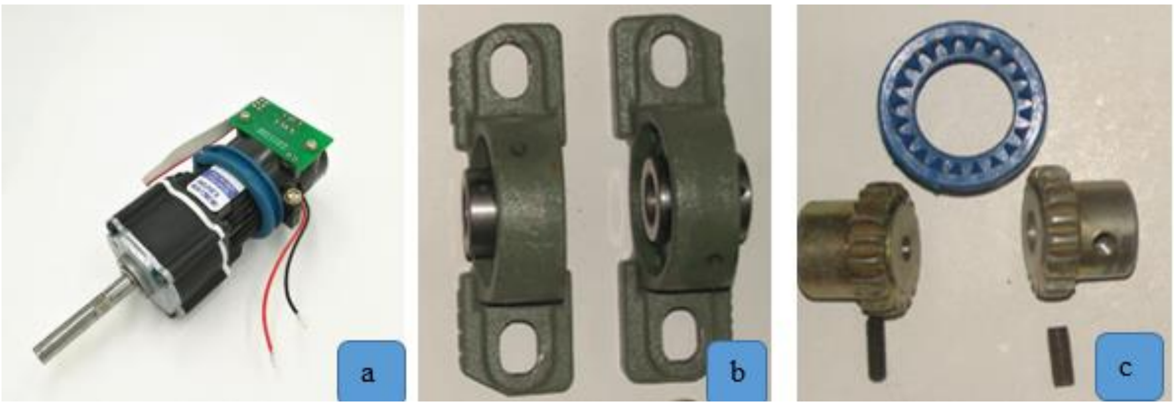

Figure 3.25 Equipment purchased.

After completing the parts of the wheel can assembled as shown in figure 3.27 as this shape is for one set of wheels and figure 3.28 shows the assembly of the four sets of wheels figure 3.26 shows the all parts from one set before assembly.

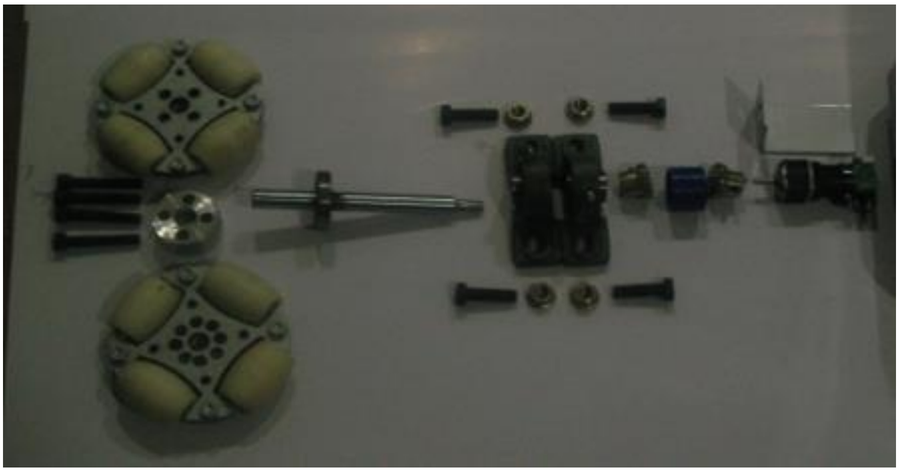

Figure 3.26 One set of Omni wheel before assembly.

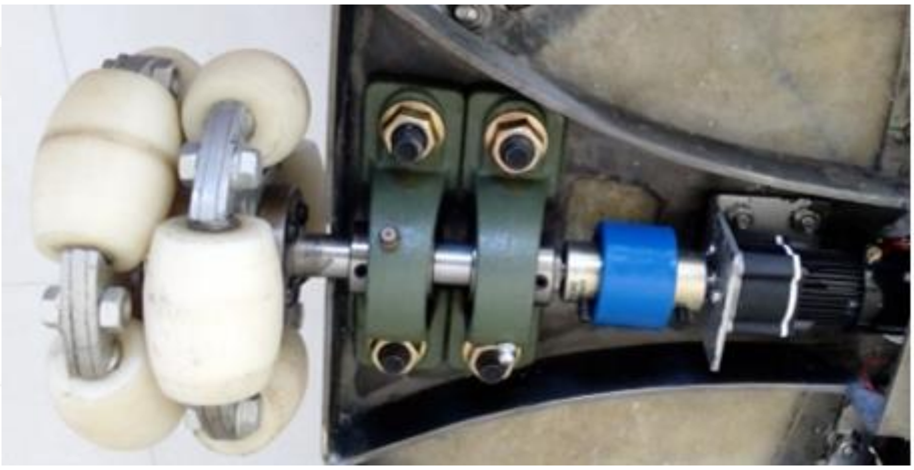

Figure 3.27 1 One set of Omni wheel.

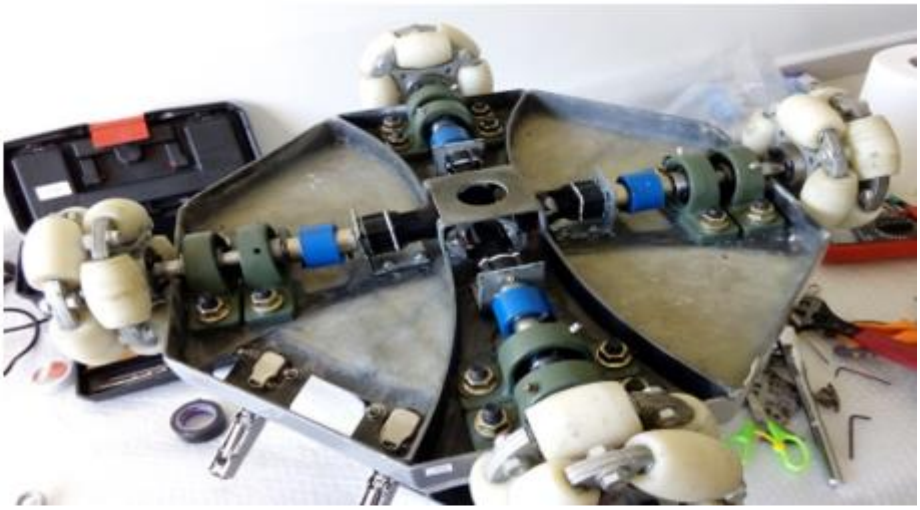

Figure 3.28 Assembly of the four sets of wheels.

3.1.2. Base body

Base body is the body that holds most of the vital robot parts also it stores the microcontroller and the all-electrical system and linked to the Dc motors from the bottom and from the top connected with rotary joint to upper body. Additionally the omni wheels are connected to the base body as well. The issue that is encountered was that is needed a specific shape and specific size that was not available on the market. For this reason, can be used CNC, plasma cutter to create the base. Before cut the metal though its need it to plan the shape that is need it by CAD /CAM where the parts are drawn by the AutoCAD program and then manufactured by CNC Plasma cutter.

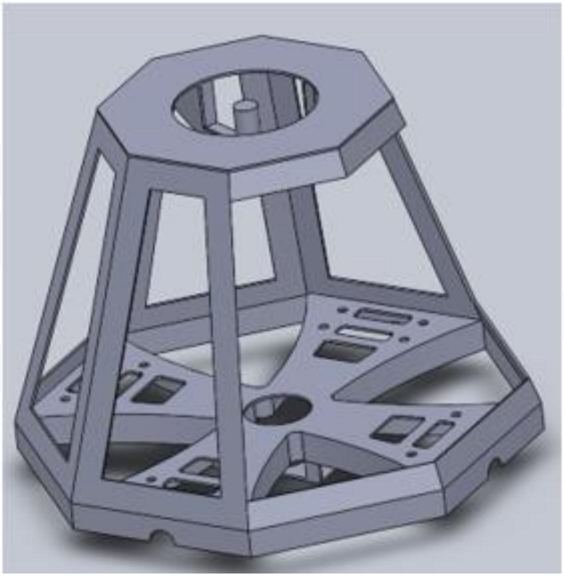

Figure 3.29 Main body Abstract Plan.

Figure 3.29 was the initial plan, base that will be folded and create the desire shape that will have enough space to hold most of the parts.

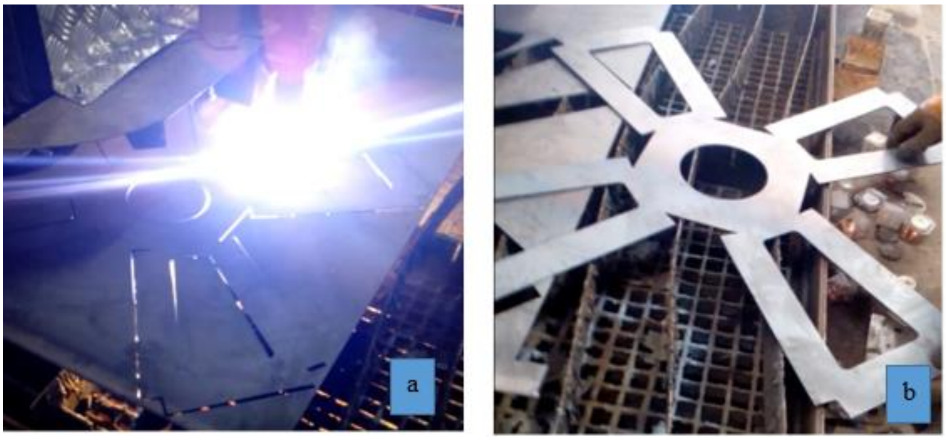

Figure 3.30 Plasma-cutting process.

To create this, can be using steel plate and with a CNC plasma cutter, its have created the original base. The base created as it can be seen in figure 3.30 (a) showing plasma cutting process and figure 3.30 (b) shows the largest part of base body, after the cut the main base we folded the rears of the rears of the metal as shown on figure 3.31 with the required angle as in design.

Figure 3.31 Largest part from base body.

Then close the wings and folded all the edge as shown on figure: 3.32 (a) show the top view and 3.32 (b) showing the bottom view.

Figure 3.32 Largest part from base body after folded the wings.

After folding all the edges, have welded the these parts together with a base to solidify our construction, and also according to the plan has been cut the piece according to the pre-design and linked as shown in figure 3.33 .


Figure 3.33 Largest part from base body connected with base.

After that can be manufactured base from rotary joint and inked with upper of base body, the figure: 3.34 show rotary base and figure: 3.35 show rotary base to connect with base body.


Figure 3.34 Rotary base.

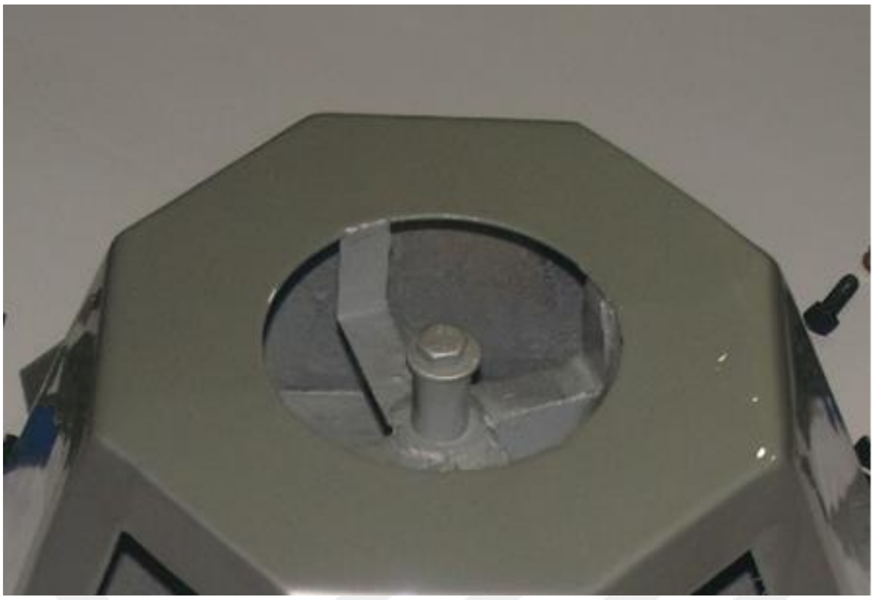
Figure3.35 Rotary base to connect with base body.

Finally, it can to obtain final base body shape, the figure 3.36 show that shape.

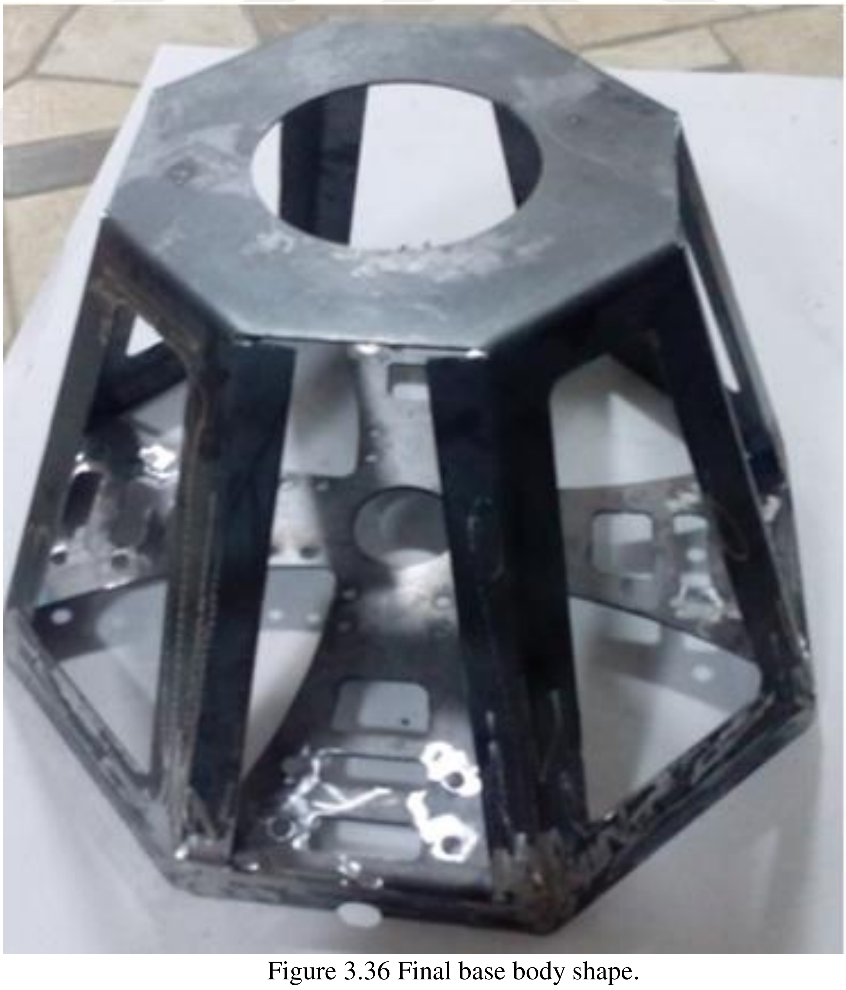
Figure 3.36 Final base body shape.

Figure 3.37 shows the shape after the Painting and closed the openings to be in the form of a locked box.

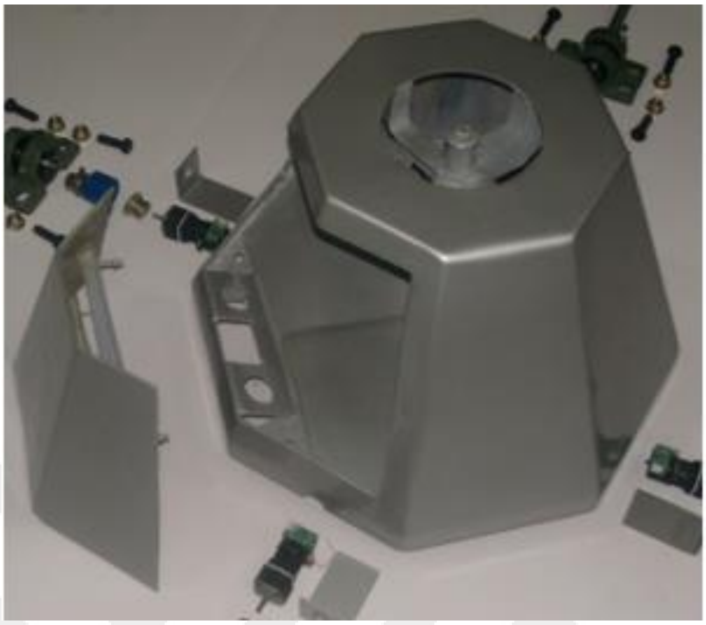

Figure 3.37 Final shape from base body.

3.1.3. Upper body

This part is centered on the base body through the rotary joint from the bottom and from the top holds two rotary joints of the arms and must be strong enough to ensure stability and rotation well, the figure: 3.38 showing shape of plan from upper part.

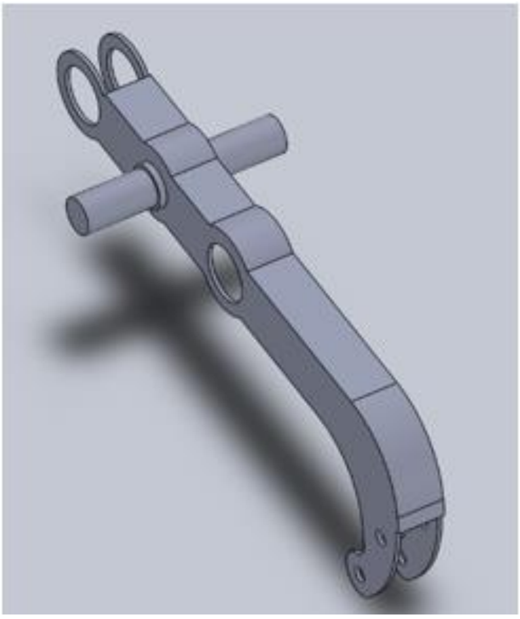

Figure 3.38 Plan from upper part.

According to the dimension in the design and the same the previous way to manufacture the base body is cut parts by CNC plasma machine and welding all the parts together figure3.39 show this shape

Figure 3.39 Upper body

3.1.4. Rotate joints

The design of this robot contains three rotary joints of this type, one of which is between the base body and the upper body and the other two joints are for the rotation of the shoulders of the arms figure 3.40 shows a set of these joints assembled.

Figure 3.40 Rotary joint assembly.

The building of such joint would require several specific parts. For reasons of ease of manufacturing a car vehicle tire Ball Bearing joint was chosen. As well as the car vehicle joints some other gears were used as they were readily available in the local market, as shown on figure 3.41.

Figure 3.41 Rotary joint parts before machining.

To linked these parts together, some machining were involved and the parts were configured and put together as shown in figure 3.42.

Figure 3.42: rotary joint parts after machining.

3.1.5. Arms

The design of this robot consists of two arms. Each arm has several sub parts, these are the Shoulder, the Actuator, the Upper Arm, the Elbow Servo Motor and finally the Forearm. The following paragraphs explain the manufacturing process involved in making of these subparts.

- **Shoulder**

The design of the Shoulder and also that of many other parts of the arms was first carried out using AutoCAD program. Once the desired shape was drawn according to its function and related stress stain calculation, the drawing was then materialized to actual parts by the use of CNC Plasma Cutters. Figure 3.43 below shows the pair of Shoulders as being assembled and welded after the CNC Plasma Cutter has produced the various parts.

Figure 3.43 Shoulders.

- **Actuator**

The Actuator was purchased from the local market. This type of Actuator has proved to be successfully able to achieve its function within the overall design of the robot. Two of these actuators were needed for the arms, figure 3.44 shown this type of liner actuator.

Figure 3.44 Linear actuator.

- **upper arm**

The design and the subsequent manufacturing of the Upper Arms involved the use of steel parts as well as fiberglass molding to take advantage of lighter weight components. The steel parts were again drawn first using AutoCAD and then have the parts cut using CNC Plasma cutter. Figure 3.45 (‘a’ and ‘b’) below, shows two views of the steel parts of the Upper arms.

Figure 3.45 Steel part in upper arm.

As the steel parts of the Upper Arms were completed, the fiberglass of the complete Upper Arm was under taken. A wooden mold was attached to the steel parts and layers of Fiberglass were added to the steel parts until a thickness of 3mm Fiberglass was achieved. Figure 3.46 below shows this process.

Figure 3.46 Upper arm working to fiberglass.

Figure 3.47 shows the Upper Arm component finished after the steel and fiberglass process was completed. The figure show the Upper Arm in its final position in the Omni Robot.

Figure 3.47 Upper arm.

- **elbow servo motor**

Figure 3.48 shows a typical Servo Motor used in this robot design. This particular Servo Motor was utilized for this design, as it was readily available in the local market.

Figure 3.48 Servomotor.

- **Forearm**

The design of the forearm needed a through consideration for weight to minimize over loading on the motor function. It is for this reason that the use of fiberglass was chosen to manufacture the forearms. fiberglass by nature is strong and lighter weight than steel, and could be used for the arm movements. To achieve this a combination of wood and fiberglass were utilized to manufacture these forearms. The fiberglass was built up of many layers around the wooden mold to establish a thickness of some 3mm which proved to be strong enough for our purpose. Figure 3.49 shows the process of manufacturing the Forearm using wooden mold and also shows the application of Fiberglass to the mold.

Figure 3.49 Forearm working to fiberglass.

Figure 3.50 Forearm.

Figures 3.50 shows the completed and manufacture Forearm, as being weighed on a weighing scale. The benefit for the use of Fiberglas is well demonstrated by the shear lightweight of the finished product.


Figure 3.51 Assembly arm.

After the manufacturing of all the Forearm components and have these parts assembled, the result is shown on Figure 3.51, the figure shows one set of arm, the robot requires two sets of this Forearm and the following figures show various parts of the robots, before and after assembly. Finally, the shape 3.52 shows parts of base robot before assemblage and figure 3.53 shows all parts of robot before assemblage and 3.54 shows all parts of our robot before and after assemblage.

Figure 3.52 The parts of base body and Omni wheels.

Figure 3.53 The all parts before assembly.

Figure 3.54 The final shape of a robot.

4. ELECTRIC, ELECTRONIC, SOFTWARE AND PROGRAMMING

4.1. Hardware

In this research, robot building requires six elements of electronic devices.

These are:

- Micro-controller.
- Motors.
- Drivers.
- Remote controller.
- Power supply.
- Wiring.

Three types of motors were used for this Omni robot. All the motor and servos needed controllers and drivers to connect to them. It was necessary to connect these devices by cables. This was done by wire. Two twelve volts batteries were select as an energy source for the remote controlling purposes, a suitable remote control system was selected. The following paragraphs will describe each of these hardware's and their use to enable a functional robot.

4.1.1. Microcontrollers

For this specific project, Arduino was used as core microcontroller. Arduino is an open source hardware and software. Arduino microcontrollers are very popular within the academic community due to open source nature of the Arduino project. Arduino has started in 2003, and since then it has seen various adaptation in many projects, due to the nature of the open source projects, Arduino had grown a large community that is now producing several boards and add-ons. Additionally, several code examples exist, and the community is well documented. The microcontroller is using a same named IDE for the programming of the flash memory of the board. Arduino boards are relatively good choices for project such as this. This is due to the fact that Arduino offer boards that can manipulate DC motors which would be used for locomotion and its supporting servos that could be used for forward or reverse kinematics for the arms of the robot. Connectivity to the computer is through Serial port (USB), additionally Arduino can receive several expansions that would allow the remote control to be functional. The board itself is supporting digital and analogue (I/0) which are compatible with the motors used in this project. Arduino has Bluetooth and Wi-Fi capabilities that are used to connect the remote controller. Additionally, the USB port was used for connect to personal computer, Figure: 4.1 shows the Arduino Mega that was used in this research

Figure 4.1 Arduino Mega.

4.1.2. Motors and actuators

DC Motors, Servo Motors and Linear Actuators were used in the design of this Omni manipulator robot. Two types of DC motors were used in the design of the Omni robot. Type “A” motors for driving the Wheels, and type “B” motors for driving the Rotary Joints. An example of Type “A” motor is shown in figure 4.2, where Figure 4.2 “a” shows the Dc Motor and figure 4.2 “b” shows such motor fully installed in the Omni Robot. Four such motors were used in the robot design, each driving one of the wheel sets.

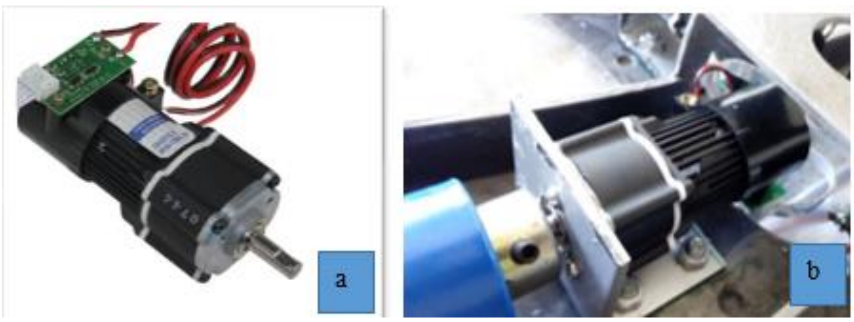

Figure 4.2 DC motors for control the Omni wheels.

The second type of DC Motors "B" was used for the movement of the Upper Base Rotary Joints. Three of such DC Motors were used in the design of the Omni robot. Figure 4.3 shows a typical example of such DC Motors. These motor have a gear box built into them. The selection of such motor was achieved according to the criteria of the design of the Omni robot such as the rotary torque required and the Revolution per Minute (RPM). These motors also include an encoder built into them. Although these encoders were not utilised in this thesis, but it would be a very useful component if and when future improvement were needed in the design of the robot.

Figure 4.3 DC motor for rotary joint.

In addition to the DC motors, omni robot would require servos to control the arms. These servos. These servos are very precious, and it is this precision are is so very much required in robotics. Figure: 4.4 below shows a typical servo for moving the arm .This type of servo are capable of moving in increments of degree of fraction of a degree, making them ideal for such applications and two of these motors were prepared for this thesis were used in the arm elbow.

Figure 4.4 Servomotor used to elbow of Arm.

Finally, as for the Linear Actuators as in figure 4.5, in the design of this Omni robot, three such Linear Actuators were used for connecting the joints. This type of Linear Actuators provide adequate push force which is much needed in this case for lifting the upper body of the robot and also for lifting the shoulders.

Figure 4.5 linear actuator.

4.1.3. Drivers

Drivers must be used between the DC Motors, Servo Motors and the Controller Unit. In this search six of the Dual 15A H-Bridge DC Motor Drivers were used. Four of these drivers (Powered by 12 volt) were used to control the four Wheel DC Motors as well as the two Rotary Joint DC Servo Motors. The other two Dual 15A H-Bridge DC motor Drivers were used to control the three Linear Actuators. For the latter, the Dual 15A H-Bridge DC Motor Drivers were powered by 24V Power supply. Each of this type of drivers is capable of controlling up to 2 DC Motors. Furthermore, the drivers can be connected to each other. These type drivers were selected according to the requirements of the robot's electrical system. Figure: 4.6 show a typical Dual 15A H-Bridge DC Motor Drivers.

Figure 4.6 Dual 15A H-Bridge DC motor driver.

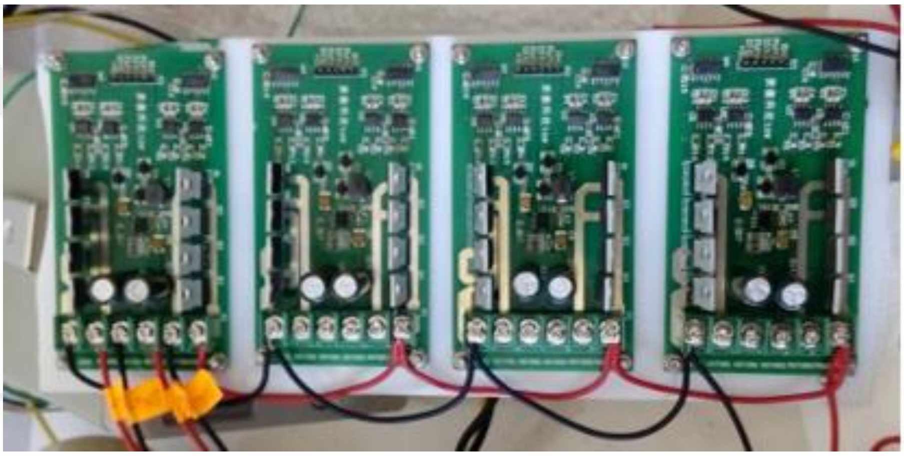

Figure 4.7 Dual 15A H-Bridge DC Motor Drivers installed on plastic board.

Figure 4.7 above shows four Dual 15A H-Bridge DC Motor Drivers installed together and ready to be built into the Omni Robot. This typical setup is powered by12V power supply.

Specifications of Dual 15A H-Bridge DC Motor Drivers

The drive features a complete two half-bridge driver chip with low resistance N-channel MOSFET components. Complete two half-bridge driver IC and reliable drive, so that the MOSFET switching losses to a minimum. Improve power utilization. MOSFET driver chip hardware comes with brake function and energy feedback. And the dimensions of this driver is 11cm x 5.8cm, The drive can operate at 0% -99% duty cycle of the PWM modulation, the motor drive voltage can be sufficient.

Control Signal:

The motor is transferred: DIR = 1 PWM = PWM

Motor Reverse: DIR = 0 PWM = PWM

Parking brake: DIR = X PWM = 0

Motor and power connections

Then the power of positive POWER, GND for negative one, figure 4.8 shows terminal connections for the motors and it can be two motors connected.

Figure 4.8 Terminal connections for the motors.

Figure 4.8 (a, b) shows Place the drive cable connection. MOTOR 1 and MOTOR 2 connection on the drivers

Specifications:

Rated voltage: 3V to 36V

Rated current: 15A

Peak Current: 30A

4.1.4. Remote control

A thorough search was conducted to find a suitable means of control. Two optioned were identified. The first option was to use Smartphone and the second option was to use Hitec Aurora 9. The smart phone proved to be unreliable and the connections were unstable which resulted in limited control of the robot. The Hitec aurora 9 was by far the best option for the application. The IDE were set up so that the Arduino receives input from the Aurora

9 controller, the whole process was compiled to update the microcontroller. This complex coding was normal with the exception that the input was received from Aurora 9.

Figure 4.9 Aurora 9 Hitec Control.

figure 4.9 above shows the Aurora Hitec control console, the specification (as obtained from HItec site) is as follows:-

-AFHSS 2.4GHz / PPM / PCM Compatible

-Easy to Read 5.1 Inch Wide Backlit Touch Screen

-Customizable Menus

-One-Stop Model Type Setting

-3 Multi-Tasking Digital Trims

-Fully Assignable Control Switch, Knob, Stick and Digital Trims

-Highly Sensitive 8 Ball-Bearing Gimbals with Adjustable Tension

-Full-Sized Comfortable Hand Grips Featuring Top Quality Elastomer

-Selectable Control Stick Mode / Change Hardware without Opening Case

-Power Management System (Adjustable Backlight & Auto Shut-off Time)

-Digital Trim Nano-Adjuster (Approx. 0.025deg per step up to 5deg)

Standard Programming Features[6]

-9 Assignable Control Channels
-3 Model Types (ACRO/GLID/HELI) Programming
-30 Model Memories
-20 Character model name
-8 Flight Conditions with 10 Characters
-Throttle Lock
-Fail-safe
-Channel Function
-EPA
-Sub-Trim
-Servo Reverse
-Servo Speed (Up to 25 sec in Each Direction)
-Servo Monitor (Monitor & Servo Test)
-8 Programmable Mixes (5 x 2-Point , 3 x 7-Point Curves)
-Trainer Port

To optimize the full function of the Aurora control, one set of control channel was dedicated for the wheel movements whilst another set of control was assigned to function the DC motors for the movement of the omni robot

4.1.5. Energy system

For the power component of the robot design, there optioned were considered. The first option would have involved using power cable directly to energize the robot. The limitation of mobility has rendered this option nil and void. A second option would have been to use a petrol engine to provide power to the robot. This too has had its problems in space availability, integration such power source with microcontroller, as well as the extra weight that such petrol engine will cause. For all the previous reason the petrol, option was also dismissed. The third and most successful option was to use battery power pack. This by far was the best option for this design. One battery source was proved to be inadequate, so the use of twin battery power supply us a figure 4.10, was the final acceptable option to go forward.

Figure 4.10 The batteries.

The power for the remote control was achieved by using standard dry power gel batteries.

4.1.6. Wiring

In this section, explain how cables connected between motors, drivers and controllers. Each DC motors withe actuators needs two cables from the motor to the driver and then to the controller and for the servomotors need three cables two for power and one goes to controller in our robot has seven DC motors 12 voltages. and three actuators 24 voltages and two servo motors 6 voltages so each DC motor with actuator has two cables goes to drivers in this system DC motors cable goes to 12 volt drivers and actuators cable goes to 24 volt drivers. Each drivers for each motor has PWM and DIR output cable goes to controller figure 4.11 shows diagram to cables connection. In addition, figure 4.12 shows cables are install in place

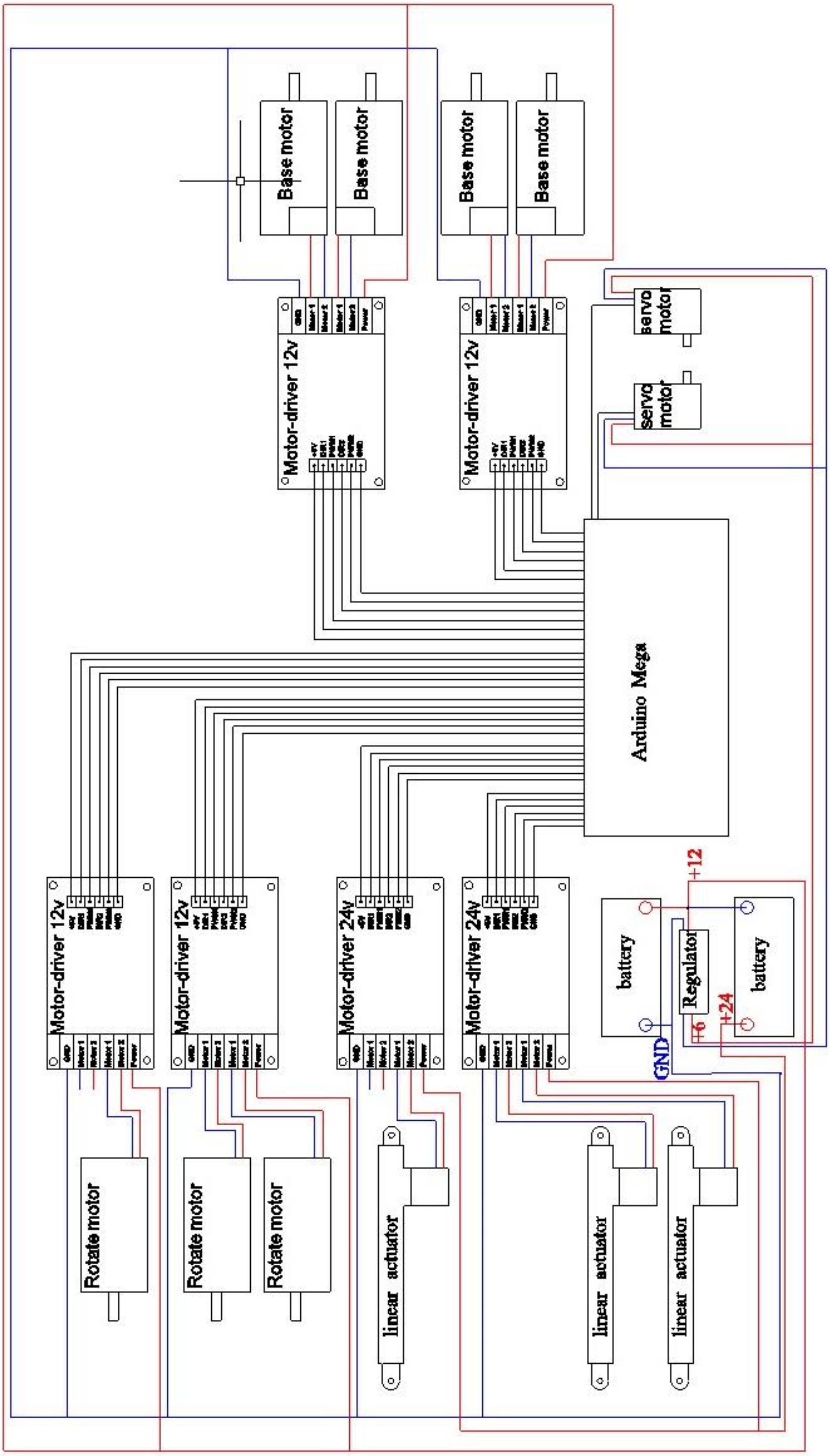

Figure 4.11 Cables connection diagram.

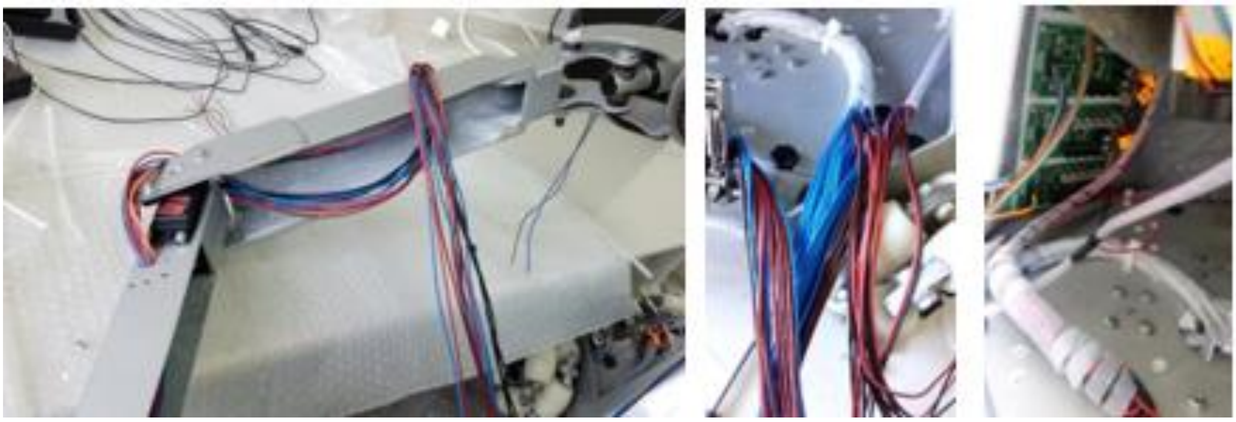
Figure 4.12 The cables are install in place.

4.2. Software & programming

4.3. Arduino 1.8.7

Arduino 1.8.7 is the latest stable IDE (Integrated Development Environment) for Arduino. IDE are special software that allows the programmers to write, compile and debug code. Nowadays some popular IDE like visual studio are allowing the generation of GUI through them. Arduino 1.8.7 is IDE that has been written in java and it can be easily connected to the Arduino system and update its flash memory given that the necessary connections have been made and that drivers of the parallel have been installed. Arduino 1.8.7 allow coding in both C and C++.This allows the usage of object-oriented programming for more complex applications. Some other features of Arduino IDE are the fact that it can monitor the traffic of the serial ports this allows instant debugging. The latest IDE also supports Bluetooth and Wi-Fi, which allows the installation of Wi-Fi or Bluetooth. The receiver microcontroller if setup properly can receive the input from the controller.

4.3.1. Arduino coding

Arduino was used for manipulating the DC motor. The code listed below has been written to achieve this task. First the code declares which pins are used for the Arduino to send the power though them. In the next setup function, the code receives input from the serial port, in the main loop. Then it checks if the serial post is available. The code will then make a validation to check if the speed is acceptable for the motor and finally it sends the power to the pins to activate the DC Motors Movement, and Servo Forward Kinematic movement to move the robot. The code uses four arguments. Each argument will be translated into movement. To make the Arduino move the code must first declare the four servos. After declaring the servos, a function is created that will take an argument a one-dimensional array which contain four elements. Each element will contain a forward kinematic command; this command will make a servo rotate. To ensure that the movement is valid and to secure and nullify any human mistakes this rotation is saved into a one-dimensional array. Additionally, two extra arrays are added that will keep the lower and the upper limit for the servos. For a movement to be valid it must be between the upper- and lower-degree limit. After a movement is completed, the new servo position will be stored into an Array. The following is coding process short example for our robot which is put to Arduino program

```
const int base_motor_a_pwm =  2;
 const int base_motor_a_dir =  31;
 const int base_motor_b_pwm =  3;
 const int base_motor_b_dir =  32;
 const int base_motor_c_pwm =  4;
 const int base_motor_c_dir =  33;
 const int base_motor_d_pwm =  5;
 const int base_motor_d_dir =  34;
  const int center_rotate_pwm = 45; //no pwm only on off
 const int center_rotate_dir = 44;
 const int R_shoulder_rotate_pwm = 6;
 const int R_shoulder_rotate_dir = 35;
 const int L_shoulder_rotate_pwm = 7;
 const int L_shoulder_rotate_dir = 36;
 // actuators
const int R_shoulder_up_down_pwm = 8;
const int R_shoulder_up_down_dir = 37;
const int L_shoulder_up_down_pwm = 9;
const int L_shoulder_up_down_dir = 38;
const int center_up_down_pwm = 10;
const int center_up_down_dir = 39;
```

4.3.2. Wireless control

There are three ways to setup remote control in Arduino systems. The first one is via Bluetooth, the second is by Wi-Fi and the third way is via Radio. A detailed explanation on how to set up each of those can be found on [7].The Bluetooth can be a good choice if the use of Smartphone is preferred for controlling the robot this choice is limited for close distance application. The Wi-Fi on the other has higher speed connection but is also good for relatively close distances. For these reasons, it was decided to use Radio. This choice was compatible with aurora. To do this a server client system has to be created the server was the Arduino board, which receives the signal from the client which was the remote control. A detailed explanation can be found on how to setup the remote control to the robot. More specifically first the serial port was opened then the server was set to receive from channel 1, and then the RF signal was set. The client then was ready to receive

```
void setup()
{
  Serial.begin(9600);
  while (!Serial)
    ; // wait for serial port to connect. Needed for Leonardo only
  if (!nrf24.init())
    Serial.println("init failed");
  // Defaults after init are 2.402 GHz (channel 2), 2Mbps, 0dBm
  if (!nrf24.setChannel(1))
    Serial.println("setChannel failed");
  if (!nrf24.setRF(RH_NRF24::DataRate2Mbps, RH_NRF24::TransmitPower0dBm))
    Serial.println("setRF failed");
}
```

Figure 4.13 Code for Radio Signal Client/Server Setup.

Figure 4.13 shows code for Radio Signal, the code applies for the setup of the Server as well. After the setup is completed data can be transferred both ways. From server to the client and vice-versa

5. THE RESULT

5.1. Result and discussion

After completing, the work in this thesis and obtained a robot completed in mechanical and electronic design and completed manufacturing it can be evaluated or understand the following

- The Omni robot was able to move in 360-degree space, it was able to instantly turn and change direction. Due to its rather small size, it could go under large furniture like tables and it was able to interact with objects above its height. Above small tables, beds it was able to even reach door handle in relatively high speed.
- One of the limitations of the robot was that it lacked hands/grippers. This resulted in limited object manipulation. Furthermore, the robot lacked cameras and other sensors, this was a great disadvantage limitation as it limited the distance between the operator and the robot. The operator must walk along side with the robot.
- Another limitation of the Omni wheels was that they lack friction; this made the robot slide and limited its speed. Furthermore, if the terrain is slippery the robot may be unable to move.
- The remote control, on the other hand, had very good reach. The remote signal can almost reach 1 km, which was much more than the scope of this research, The advantage of this distance was not fully capitalised as the robot has no way to operate automatically and that it cannot send visual signal back to the operator.
- The robot due to its design can carry heavy weight that can reach several kg.
- The design of the arms also allowed it to move large items. The arms base had 360 degree of freedom which allowed the robot to manipulate items that are surrounding it without the need of moving. The arms had a limited 180 degree of freedom which again was more than enough for this project.

Finally, works and/or functions for use this robot to completely or in part for example: Demining, Military uses, Polluted (dirty) places, for study or research, etc... It can be used for many purposes, by making simple changes according the new work.

5.2. Conclusion and future work

This thesis did yield some successful results since it proved that an Omni robot could manipulate objects in higher places without the need of extending its body or losing speed or stability. Additionally, due to the Omni nature of the robot, the robot can manipulate objects in tight spots in 360 degrees, however future work is needed to further enhance the performance of this existing Omni Robot. It is believed that this research has paved the way for the first step of Omni robots. Future work should involve the extension of the arms of the robot and the adding grippers to these arms. This will allow the future robot to better manipulate objects around it. As well as this, the future additions of an ultrasonic ring surrounding the robot will secure it from human mistakes and give it some insights to the operator. Another future work should be the addition of sensors to the grippers to allow reverse kinematics and automation regarding the grapping and manipulation of objects. Another problem that needs to be tackled is that the operator has no visual feedback. This can be solved by adding cameras to the arms and to the body of the robot that will send visual signal to the remote control allowing the robot to travel further and be away from the operator. Finally, we believe that the Omni wheels should receive an upgrade regarding the friction between the heels and the ground surface. It is believed that a different type of material could be used for the cylindrical conical wheels. Perhaps the need to change the Teflon wheels to a plastic with better friction coefficient to improve the friction and allow the robot to move in any terrain. As a conclusion, this project has managed to create a stable Omni robot that was able to manipulate objects in higher places.

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Curriculum Vitae for Hemin Jamal Mustafa

Profile Summary

Hemin Jamal Mustafa is a Mechanical Engineer qualified to BEng level and he studies MSc. mechatronics (control system), and he is a permanent member of staff of Computer Science Institute Sulaimani, Iraq as an engineer. Additionally, Hemin is working as Dr. George's research assistant at the SR1 (Sulaimani Robot one) research project. Hemin's expertise includes mechanical design using tools such as AutoCAD and AutoCAD 3D and manufacturing, using traditional machinery and CNCs. His soft skills include hardworking, team player and good analytical skills.

Academic Qualifications

Fırat Universities ELAZIĞ/TÜRKİYE	2016 – present MSc. mechatronics (control system)
Sulaimani technical college, (now called Sulaimani polytechnic university) Sulaimani, Iraq	**BEng in Production and metallurgy engineering** BEng project title: Manufacturing Explanatory Models of Al for Mechanical drawing subject. Degree award date: September, 2011, Result: 61%
Dor technical institute, Salahadin, Iraq	**Diploma in Production and metallurgy Eng.** Result: 72%

Industrial Appointments

Computer Science Institute, Sulaimani polytechnic university, Sulaimani, Iraq	**Engineer** 2010 – present, Engineering department

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Kurdish:	is my mother language
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