

Design and Fabrication of Robotic Arm for MIG/TIG Welding



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Design and Fabrication of Robotic Arm for MIG/TIG Welding

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Abstract

This work concerns with the design and fabrication of a five degrees freedom robotic arm, which is intended to weld steel plate thickness ranges from 2mm to 10mm using MIG/TIG welding process. It has been made with four flexible joints such as a gripper, three rectangular shaped links, a rotary table, a rectangular platform and a rotating wheel. Each angular motion is motorized by a servo motor. Moreover, the angular position of each servomotor shaft is controlled by a signal from an Arduino Mega 2560 microcontroller which executes by an open source programming language called Visuino code. The design process involves numerous analytical calculations, mechanical properties calculations and prototyping for better functionality.

During the thesis work, different areas of hardware and software developing process parameters of robotics arms had done. These parameters mainly focused on the analysis of kinematics, force/torque, control system for hardware designing, FEM analysis of the arm, and robot coding's. The end effector of the robot arm performs different additional activities like gripping materials to move from one place to another. The robot arm controlling system was implemented with a series of five potentiometers and additional DC motor speed and direction control devise. A pre-test of the robotic arm has analyzed after completing the programming and assembling. The automation for MIG/TIG welding configuration are performed and tested. Some of the welds were performed under the automation condition.

The outcomes of a robotic arm are able to perform gripping, lifting, moving and welding are designed and manufactured. While performing the welding operations, the following drawbacks are observed, uneven vibrations, difficulty in transferring the full torque. Even though, the MIG welding operation has performed on 2mm steel material. In positioning the torch, weld gap is maintained properly by the arm. In consideration the negative factor addressed above the following weld defects are majorly seen on weld material. High spark, slag, weld jump, deep penetration, under penetration, weld line deviation the major defects observed.

Keywords: - Robotic arm, arc welding, degrees of freedom, Servo motor, Microcontroller.

Authorship

I certify that this thesis work titled “Design and Fabrication of Robotic Arm for MIG/TIG welding” is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

Melesse Hailu Belete,

With regards,

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My greeting is infinity for almighty **GOD** the guardians of the world for his mercy, kindness and love. I greatly acknowledge my supervisor **Associate Professor Perumalla Janaki Ramulu (PhD.)** for his greatest support in supervising in each steps of the thesis work, guiding to prepare this document and allowing his office and giving his time to complete this research.

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GOD IS GOOD!!!

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Chapter 1: Introduction

1. Introduction

1.1. Background

In the industrial world, automation is one of the most important elements for development which to reduce the need for humans and increase efficiency and productivity. The field of automation occupies large areas, mostly in industrial manufacturing and in addition to this; automation is applied to build a lot of sophisticated equipment which are used daily such as medical equipment (x-ray machines, radiography etc.), refrigerators, automobiles etc. Among all of these outcomes, the robotic arm is one of them, which is widely used in industrial purposes. In all robotic functions, the robotic arm is one of the important functionalities emphasize in the automated production process. The robotic arm can accomplish the operation of the equipment, it is a kind of indispensable equipment applied for the mechanization and automation. Robots are designed and fabricated to perform variable works like painting, cutting, picking and dropping, loading unloading, welding, transporting, and so on.

The end effector or robotic arm, were designed to perform any desired task such as welding, gripping, spinning etc., depending on the application. As an example, robot arms in automotive assembly lines perform a variety of tasks such as welding and parts rotation and placement during assembly. In some circumstances, close emulation of the human hand is desired, as in robots designed to conduct bomb disarmament and disposal (Williams, December 2016). A robotic arm can be compared to a human hand. It has a free rotating joint (rotation) and a translational joint (displacement) for the movement of the arm. This arm movement is usually driven by an electric driver (motor) or a pneumatic and a hydraulic system (pistons) (Williams, December 2016). These actuators are controlled by a microcontroller (CPU), usually programmable and made to perform a set of sequential tasks. Most of these robotic arms are designed to be used for industrial purposes for fast and reliable performance, helping for mass productions.

1.2. Statement of the problem

Now a days competing in the global market with a product have high quality and high precision becoming essential. In addressing such problems, mechanization of the manufacturing system is one of the latest traditions. In Ethiopia, the automated production processes are delays far from the existing system used in developed country. If the condition continues with same pace, national industrial economy and people life style will become outdated by the technical growth of global market. Therefore, this project is induced to start and adopt a modernized arc welding process setup in-which adverse contribute the overall upgrading existing machineries and develop a new one.

1.3. Objective of the thesis

The main objective of the thesis is to design and fabricate a robotic arm for MIG/TIG arc welding process and optimize for the joint configuration.

1.4. Specific Objectives

The specific objectives of the thesis are to

- Design and fabricate a model of 5/6 DoF robotic arm
- Analyze robot program training and testing for MIG/TIG arc welding processes on steel materials
- Visual analysis of weld joints and inspect the weld quality with annual method

1.5. Methodology

The approach to complete my thesis is

- ▶ Gathering different books, journals and publication from accredited scientific society sources (i.e. teachers, websites, library etc.)
- ▶ Reading and understanding the literatures and analyze the researches identify the gaps
- ▶ Prepare a summary document,
- ▶ Designing robotic arm by different numeric approaches
- ▶ Modelling of Robotic arm using Auto CAD/ Catia
- ▶ Manufacturing Robotic arm with different configurations
- ▶ Implementing Robotic arm for arc welding and proceed to test
- ▶ Analyzing the weld results with different non-destructive tests followed by the recommendations.

1.6. Significance of research

- The significance of this thesis to show a detail understanding of robotics arm design and fabrication for arc welding.
- To understand system mechanization and the mechatronics in modern manufacturing system

1.7. Scope of the thesis

- Design and fabricate a robotic arm using standard parts like motor, microcontroller and other electrical part from market and manufacturing other mechanical parts locally
- Seam tracking mechanism used is mechanical rail system
- Flat position MIG weld test are done on steel material
- Weld joints are visually inspected and compared with manual welded with same welding type

1.8. Limitation of the thesis

- May take longer time due to standard materials are supplied from foreign countries
- May lack ability to develop a sound weld due to high sensor cost and the seam tracking mechanism used in this thesis work

1.9. Organization of the thesis

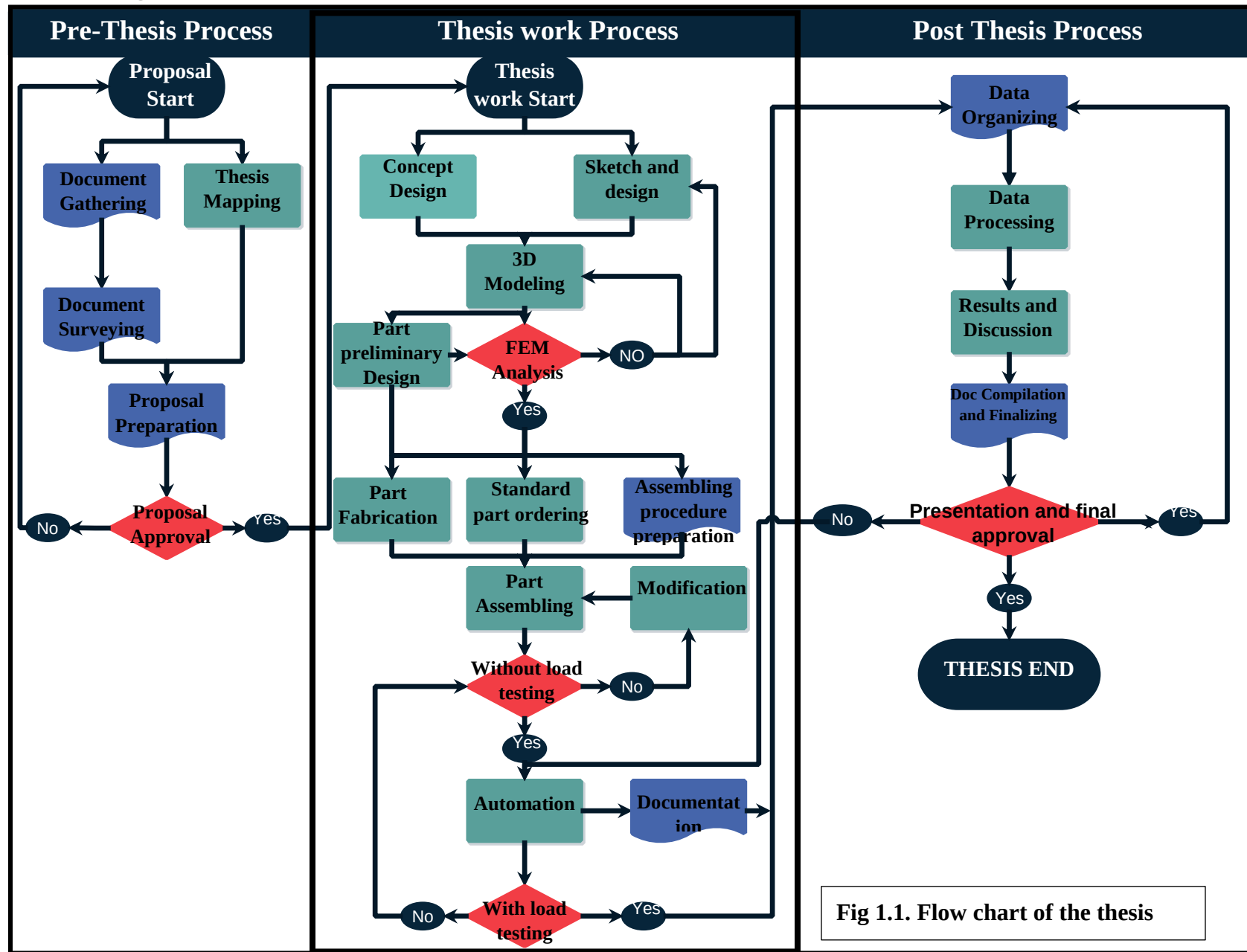


Fig 1.1. Flow chart of the thesis

Chapter 2: Literature Survey

2. Design of robotics arm for welding

2.1. Introduction to Robotic Arm and Welding

A robotic arm is a mechanical device that resembles the humanoid arm to perform different activities in industrial manufacturing system automatically through different controlling systems. The robot arm can be controlled by sensors, Bluetooth, computer program, potentiometer and the like. The degree of freedom (DOF) of a robot arm will determine the numbers of direction which the robot able to move. DOF is the numbers of direction the robot arm can move freely. The degree of freedom for robot was determined depending on the activities that, the arm intended to perform on its ranges from one to multi directions (Mustafa Suphi, 2011).

The robot can be categorized into different type depending on their intended function to perform. Some of them are medical robot, house hold robot, industrial robot etc. Here, in the literature the main focus is on the industrial robots. There are seven other types of industrial robots, they are:- Scara robots, six axis robots, dual-arm robot, welding robot, material handling robot, paint robot and assembly robot (P. Surenderath, 2015). Mechanized welding is regarded increased as an intermediate technology which helps the operators but still needs set and monitor the welding operation fairly continuous to maintain quality and productivity.

2.2. Impact of Robotic Arms in the International Economy

There were many discussions regarding Americans losing jobs to overseas manufacturers and to increased use of robotic automation, and with fair wage employment on the rise in many other countries. Amid these discussions and trends, recent studies showed that, industrial robotics impacts jobs on the economy (Ashraf Elfakhany, 2011). Creating New Jobs: Between 2008 and 2011, an estimated 500,000 to 750,000 new jobs were created because of the robotics industries. This growth is attributed to the increased level of productivity in manufacturing companies. While the robotic solution displaced a number of workers, the increased efficiency led increased productivity.

As these automated systems continue to provide value in the manufacturing industry, the demand for more, newer, and better systems continue to rise. This, in turn, increases the demand for qualified people in the robotics industry. At the same time, these manufacturing companies require people to manage, maintain, and program the new material handling robots, conveyor systems, as well as other automated solutions. By some estimates, the robotics industry generated around 170,000 jobs worldwide (C. F. Olson, 2000). The operators and technicians who use and deploy these robots account for tens of

thousands more. The indirect jobs that benefit from robotic automation include everything from retailers to distributors conceivably millions of jobs.

2.3. Impact of robotic arms in production system

The overall effects of an automation of welding on the production unit price and production volumes are shown in diagram on Fig. 2.1 below.

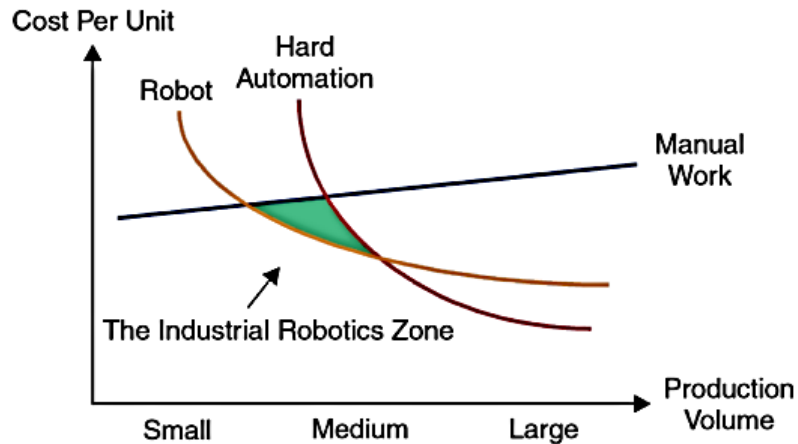


Fig 2.1 Welding automation effect on production unit price and production volume (*P Kah, 2015*)

2.1.1. Positive and negative effects of robotic arm

The Positive	The negative
Increase productivity	Cause unemployment for manual workers
Use equipment effectively	High initial cost
Reduce working costs	Designed Arm to perform specific tasks and not comparable to the human hand
Flexibility at work	Difficulty programmed to perform Accurate tasks
Get the job done in the shortest time	Needed a large number of sensors and high accuracy to perform the Complex tasks
Provide good returns on investment	And other technical problems, “especially in the fields of artificial intelligence and Machine vision”
Better accuracy in performance Ability to work in risky ways and make it safer	When the Robotic arm break down the production line will go off in the factories.

2.2. Types of Robotic Arms Configuration

The robot arm, the mathematically complex robot, goal is to find and interact with an object in the space, named end effector. The robot arm is widely used in many fields, such as industry, medicine, and in science and technology (Williams, December 2016). Thereby, there is a general structure that rules the entire robot arm, and puts a general scheme for this technology. A few types of robotic arms are given below for general overview and indicated in the Fig. 2.2.

Cartesian Robot/Gantry Robot: Used for pick and place work, application of sealant, assembly operations, handling machine tools and arc welding. It's a robot whose arm has three prismatic joints, whose axes are coincident with a Cartesian coordinator.

Cylindrical Robot: Used for assembly operations, handling at machine tools, spot welding, and handling at die-casting machines. It's a robot whose axes form a cylindrical coordinate system.

Spherical Robot/Polar Robot (such as the Unmated): Used for handling at machine tools, spot welding, die-casting, fettling machines, gas welding and arc welding. It's a robot whose axes form a polar coordinate system.

SCARA robot: Used for pick and place work, application of sealant, assembly operations and handling machine tools. This robot features two parallel rotary joints to provide compliance in a plane.

Articulated Robot: Used for assembly operations, die-casting, fettling machines, gas wiewlding, arc welding and spray painting. It's a robot whose arm has at least three rotary joints.

Parallel Robot: One use is a mobile platform handling cockpit flight simulator. It's a robot whose arms have concurrent prismatic or rotary joints.

Anthropomorphic Robot: Similar to the robotic hand Luke Skywalker receives at the end of the Empire Strikes Back. It is shaped in a way that resembles a human hand, i.e. with independent fingers and thumbs (Jegade Olawale, 2007).

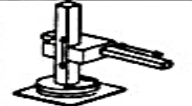
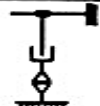
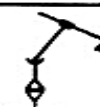
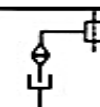
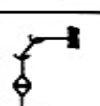
Principle	Kinematic Structure	Workspace
 Cartesian Robot		
 Cylindrical Robot		
 Spherical Robot		
 SCARA Robot		
 Articulated Robot		

Fig 2.2. Types of robot arm configurations (Jegade Olawale, 2007)

2.3. Joints and linkages

A robot mechanism is a multi-body system with the multiple bodies connected together. Each rigid body involved in a robot mechanism is called a link, and a combination of links is referred to as a linkage. In describing a linkage, it is fundamental to represent how a pair of links is connected to each other. There are two types of primitive connections between a pair of links, as shown in Fig 2.2. The first is a prismatic joint (P) where the pair of links makes a translational displacement along a fixed axis. In other words, one link slides on the other along a straight line. Therefore, it is also called a sliding joint. The second type of primitive joint is a revolute joint (R) where a pair of links rotates about a fixed axis. This type of joint is often referred to as a hinge, articulated, or rotational joint (H.H, 2005).

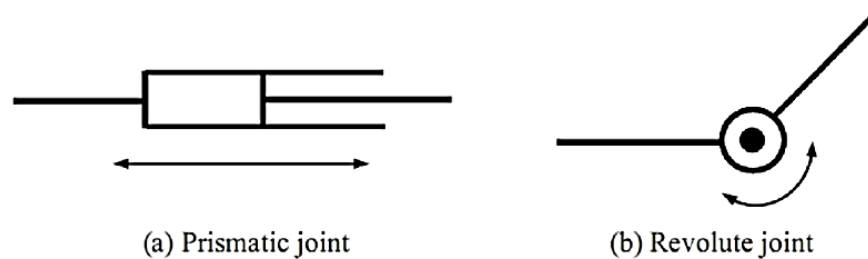


Fig 2.3 Primitive joint types: (a) a prismatic joint and (b) a revolute joint (H.H, 2005)

2.3.1. Welding and System requirements

Since welding is an important process in manufacturing mechanical equipment and needs skill and high precision. Development of welding robots can benefit manufacturer by improving welding quality, accelerating the welding process, and increasing its accuracy. Among all welding methods, arc welding is playing an important role in joining and repairing metal products. Arc welding categorized as SMAW, GTAW and GMAW are the three common types of arc welding families.

Conventionally, the most of arc welding process is performed by human operators. During welding activities manually, there are limitations such as difficulty in working chemically hazardous area, difficulty due to working and weld positions, lower weld quality and efficiency, high training cost, less ability to weld complex path, long setup time, supervisory requirements and other factors. Hence robots are emerged and still developing to tackle the above-mentioned problems and to produce more complex parts for future products. Not only the above-mentioned limitation, most of the arc welding processes are heavy and large in size to work on some maintenance due to failure of material in unpredictable location, which makes difficult and impossible to perform it with conventional methods of welding due to mobility difficulty. Hence, having a flexible and applicable methods to overcome failures of parts in complicated areas difficult to weld by manual conventional processes.

2.3.2. Robot arm in arc welding

Welding is an integral part of advanced industrial manufacturing and robotic welding is considered the main symbol of modern welding technology (Cui et al. 2013). In the earliest applications of robotic welding, so-called first-generation robotic welding systems, welding was performed as a two-pass weld system, in which the first pass was dedicated to learning the seam geometry and was then followed by the actual tracking and welding of the seam in the second pass. With developments in technology originated the second generation of robotic welding systems, which tracked the seam in real time, performing simultaneously the learning and the seam-tracking phases. The latest technology in robotic welding is third-generation systems, in which the system not only operates in real time but also learns the rapidly changing geometry of the seam while operating within unstructured environments (Pires et al. 2006). The following sections briefly discuss some of the key aspects of robotics in welding technology.

Now a day's robotic arm is performing material requires high precision welding with the quality defined and efficiently. The recent robot advanced to sense a complex weld parameters and weld quality automatically (Pi-cheng Tung, 2004). Depending on arc welding type chosen to automate the robot arm design also differs. There is consideration to be taken during the designing of the arms changes depending on the electrode type used, material type intended to be weld, welding process parameters. This consideration will decide the DOF, sensor type, arm type and size, robot controlling system.

Industrial manipulators are

- I. Open kinematics
- II. Serial links interconnected each other by revolute and prismatic joints

Open kinematics are relatively simple structure, mechanically stiffen, exhibit undesirable elastic behavior that degrades the performance of the robot under heavy and high-speed operation condition. Closed kinematics chain robots' manipulators are massive structure, high mechanical stiffness, direct drive facility, lower positioning error and power requirements, good force-velocity characteristics, existence of isotropic point within its work space.

A smooth arc welding basically depends on three phases of the welding process (Mustafa Suphi, 2011)

1. Setting the initial parameters like initial current materials, (shielding gas, filler) before welding
2. Adjust the variable during welding (current, feed rate, welding speed, welding gap etc.) during welding
3. The robot manipulator controlling mechanism through welding process

A set of experiments were conducted in a defined range of condition and the experiment results were used to determine the sets of parameters that closely meet the joint requirements. However, these types

of experiments determine optimal criteria does not always guarantee the most ideal setting or applicability to the tested condition. (P. Mechaleries, 1997) FEM method was applied to analyze the distortion for optimum tracking of the weld seam. GTAW used a high frequency arc initiation and the robotic GMAW use contact arc ignition (Yanling Xu, 2014).

2.4. Hardware design of robotic arm

The Robotic arm can be designed using the Microcontroller i.e. ATMEGA8 Microcontroller using Arduino programming. This process works on the principle of interfacing servos and potentiometers. This task is achieved by using Arduino board. The remote is fitted with potentiometers and the servos are attached to the body of the robotic arm. The potentiometer converts the mechanical motion into electrical motion. Hence, on the motion of the remote the potentiometers produce the electrical pulses, which are in route for the Arduino board. The board then processes the signals received from the potentiometers and finally, converts them into requisite digital pulses that are then sent to the servomotors. This servo will respond with regards to the pulses which results in the moment of the arm. (Gerk, 2011)

The design process is one of the most extensive and essential processes that needs to be carried out in order to produce working devices that meet the needs of consumers. From determining the problem statement and metrics, to decide the most promising design and creating prototypes, the design process guides designers to capture, integrate, and generate all the information required to make new products. In the design of automation systems, the design process has to address the interactions among the mechanical, electrical, and software components of systems in order to develop systems that have acceptable reliability, quality, scalability, and cost characteristics. This is achieved by designing the three components of automation systems concurrently through an integrated design paradigm (Reiner Schmidt, 2014). Consequently, it is necessary to teach integrated design concepts to students in programs such as process automation, electrical and computer engineering, and mechanical engineering. (Martha Kafuko, 2015)

Designing of robot arm mainly focus on the following areas (Martha Kafuko, 2015)

- a. Mechanical design of arm
- b. Selection of controllers, user interfaces, motors, sensors and other electrical components.
- c. Dimensioning of power supplies.
- d. Integration of electrical components.
- e. Establishment of the process into which the robot is to be integrated
- f. Development of the software program for the robot.

In designing there are basic points to be considered and analyzed deeply. These main criteria are

- Functionality
- Consistency/Reliability
- Manufacturability
- Motion Range and Speed
- Payload
- Reach
- Axes
- Easy constructability
- Easy maintainability
- Cost

Arms are typically defined by fourteen different parameters.

- ✓ **Number of Axes** – Two axes are needed to reach any point in a plane. Three are required to reach a point in space. Roll, pitch, and yaw control are required for full control of the end manipulator.
- ✓ **Degrees of Freedom** – Number of points a robot can be directionally controlled around. A human arm has seven degrees; articulated arms typically have up to 6.
- ✓ **Working Envelope** – Region of space a robot can encompass.
- ✓ **Working Space** – The region in space a robot can fully interact with.
- ✓ **Kinematics** – Arrangement and types of joints (Cartesian, Cylindrical, Spherical, SCARA, Articulated, Parallel)
- ✓ **Payload** – Amount that can be lifted and carried
- ✓ **Speed** – May be defined by individual or total angular or linear movement speed
- ✓ **Acceleration** – Limits maximum speed over short distances. Acceleration is given in terms of each degree of freedom or by axis.
- ✓ **Accuracy** – Given as a best case with modifiers based upon movement speed and position from optimal within the envelope.
- ✓ **Repeatability** – More closely related to precision than accuracy. Robots with a low repeatability factor and high accuracy often need only to be recalibrated.
- ✓ **Motion Control** – For certain applications, arms may only need to move to certain points in the working space. They may also need to interact with all possible points.
- ✓ **Power Source** – Electric motors or hydraulics are typically used, though new methods are emerging and being tested.

- ✓ **Drive** – Motors may be hooked directly to segments for direct drive. They may also be attached via gears or in a harmonic drive system
- ✓ **Compliance** – Measure of the distance or angle a robot joint will move under a force.

2.4.1. Hardware requirements

A robot arm is known as manipulator. It is composed of a set of joints separated in space by the arm links. The joints are where the motion in the arm occurs. A robot arm consists of the parts: base, joints, links, and a gripper (shown in Fig 2.4) (Yetim, 2009).

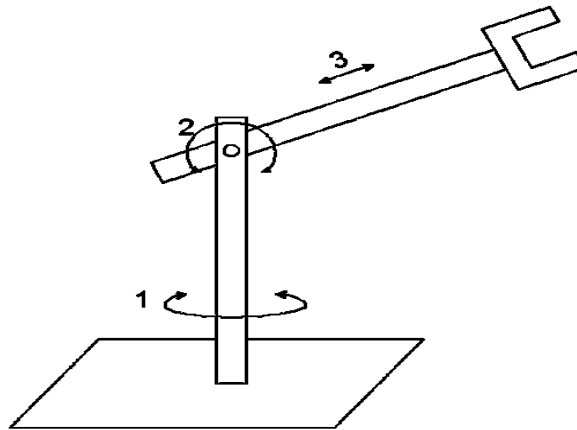


Figure-2.4 Basic robot arm. 1. Base, 2. Joint, 3. Link and the last part, gripper (Yetim, 2009)

Depending on the numbers of DOF the joints and links numbers increases. Spot welding is the first welding used robot. Arc welding using robot assistant requires

- Need to trace out a continuous path and accuracy better than that of the diameter of the electrode wire used in welding
- AC or DC servo controller motor must be able to drive the robot quickly and accurately and stop where needed without undesirable oscillation and backlash. This usually means controlling speed in relation to the distance from the desired position which requires the use of tachometer to monitor velocity and encoded to monitor the position. A short list of these components includes (Goldy Katal1, 2013)
 1. Servo motors
 2. Potentiometers
 3. Arduino board.
 4. Bluetooth module.(if necessary)
 5. Robotic arm and accessories

a. Robotic system components (S.Pachai yappan1, 2014)

Robotic system components can be grouped into one of three categories:

- i. **Mechanical Structure:** - This comprises all of the linkages and joints capable of movement.
- ii. **Actuator:** - The mechanism that provides the necessary forces to move the mechanical structure. An important factor for choosing the actuator is the existing experience with the actuators that are already used. The main reason for this is that the knowledge on how to work with these actuators is already available and the electronics drivers can be kept the same.
- iii. **Controller Circuit:** - Supplies the actuators with the input required to achieve the desired position, force, speed, etc.

2.4.2. Hardware design (Liszka, 2006)

The main requirements in designing a robot arm are

- A. Kinematics (Geometry)
- B. Force/Torque/
- C. Control mechanism

A. Kinematics (Geometry)

The kinematics is the movement of the robot's arm in the direction required to perform an activity in the given or predetermined work space for the arms. The kinematics will determine the DOF of the arm depending on the activities to be done, the stage full ranges of motion, joints limit will and the actual work space volume will be determined. The kinematics analysis of robot arm is the analysis relation between the position, velocity and acceleration of the link of manipulators. Formulating the suitable kinematics models for a robot mechanism is very crucial for analyzing the behavior of industrial manipulators. There are mainly two different spaces used in kinematics modelling of manipulators namely, Cartesian space and Quaternion space. While the orientation of a body is represented nine elements in homogenous transformations, the dual quaternions reduce the number of elements to four. It offers considerable advantage in terms of computational robustness and storage efficiency for dealing with the kinematics of robot chains (Funda & Taylor, June 1990).

Kinematics divided into two, they are indicated in Fig. 2.5 and described below

► Direct kinematics

In forward kinematics the length of each link and angle of each joint is given and the position will be calculated in the given working space. It is easy to calculate with simple homogeneous matrices.

► Inverse kinematics

The length and position of the point is given and the angle of each joint will be calculated. The inverse kinematics are hard to solve especially if the degrees of freedom becomes higher.

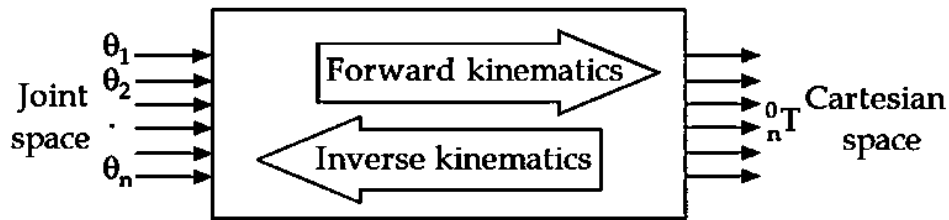


Figure 2.5. The schematic representation of forward and inverse kinematics. (Bingul, December 2006)

i. Degrees of freedom

There is different direction a robot can move in space. This different direction movements of called degrees of freedom. Serial and parallel manipulator systems are generally designed to position an end effector with six degrees of freedom, consisting of three in translation and tow in orientation (shown in Fig 2.6 and Fig 2.7). This provides a direct relationship between actuator positions and the configuration of the manipulator.

Robot arms are described by their degrees of freedom. This number typically refers to the number of single-axis rotational joints in the arm, where higher number indicates an increased flexibility in positioning a tool. This is a practical metric, in contrast to the abstract definition of degrees of freedom which measures the aggregate positioning capability of a system.

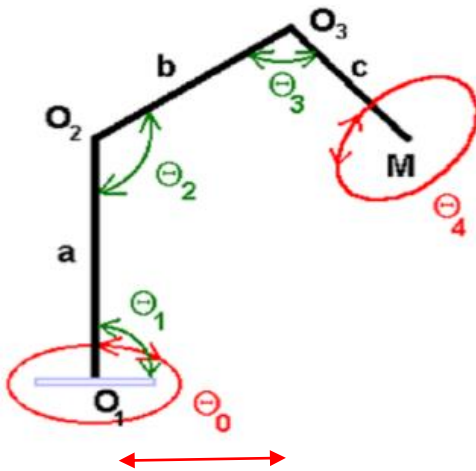


Fig 2.6 Six degrees of freedom (K., 2011)



Fig 2.7 Five degrees of robotic arm (Md. Rashed, April, 2016)

B. Force/Torque

Different robot arms can be applied in different types of activities depending on their specific requirements. The parameters are the maximum work load, self-loads of the arm other device imbedded on, the active and reaction load, working speed, effects of gravity are considered in designing the arm. The torque that corresponds to the desired trajectory can be determined in every joint. The mass for every

link is required to calculate the torque. The weight of the arm will form the biggest influence on the outcome for the torque, making an assumption for the weight of the robot arm is an iterative process. In order to find out how much torque is needed in every link the mass of the arm needs to be considered. But there are some factors that influence the mass of the arm that cannot be considered until the torque is known. These factors are the mass of the actuators and material. Therefore, a good estimation for the weight of the robot arm needs to be made the first time the torque is calculated with the Robotics toolbox (Haaren, 29th January 2012).

I. Force Calculation

In order to select the convenient motor, the force calculation to make a well-designed decision. One should make sure to not to forget, in the calculations, the maximum weight of the end effector and the weight object carried. As a first step a free body diagram was designed with the robot arm stretched out to its maximum length (Gerk, 2011).

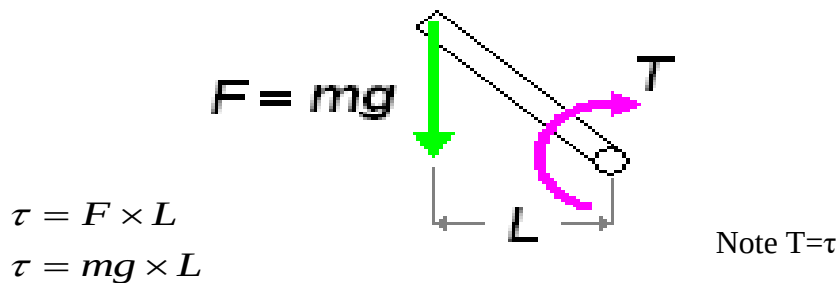


Fig 2.8 Single robot arm load diagram (Elouafiq, 2011)

The above diagram Fig. 2.8 shows the torque on the joints. Where F is for force applied; L is the perpendicular distance from pivot to the applied force; τ is the torque needed to hold the mass a given distance from the pivot.

To estimate the torque required at each joint, we must choose the worst-case scenario which is gives maximum length from the pivot

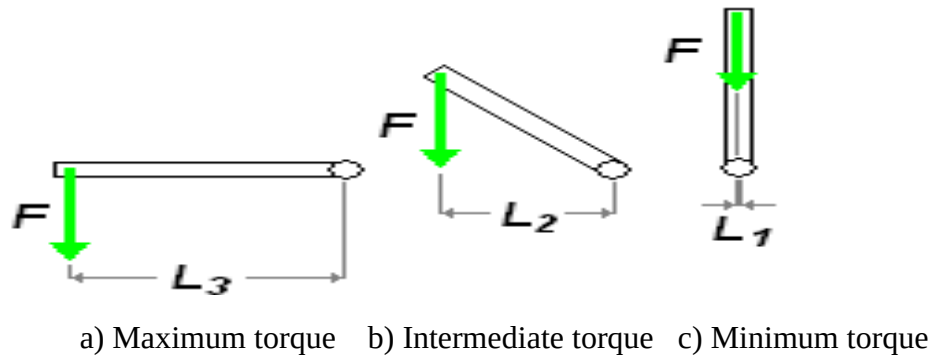


Fig 2.9. Different option robot arm load diagram depending on the perpendicular distance (Elouafiq, 2011)

As arm is rotated clockwise, L , the perpendicular distance decreases from L_3 to L_1 ($L_1=0$). Therefore, the greatest torque is at L_3 (F does not change) and torque is zero at L_1 . Motors are subjected to the highest torque when the arm is stretched out horizontally. Hence, to determine the amount of torque we need for the arm is calculated using the scenario of option “a” Fig. 2.9 above. Not only has the torque due to arm but also had to be considered during load calculation on the pivot.

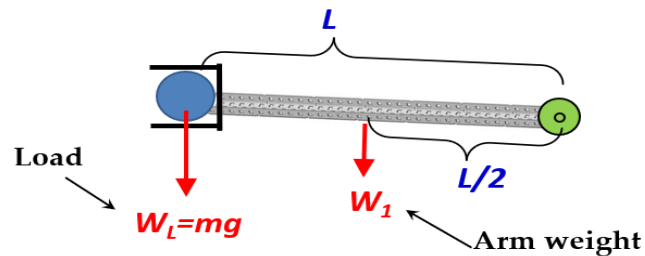


Fig 2.10 Single robot arm load diagram (Elouafiq, 2011)

W_1 is arm weight; W_2 is applied load weights; L is total length

$$\begin{aligned}\tau &= (mg \times L) + (W_1 \times L / 2) \\ &= L(mg + W_1 / 2)\end{aligned}$$

$$\tau \times rps = L(mg + W_1 / 2)(rps)(1 / \text{efficiency})$$

RMF (motor specs)

Robot arm torque

RMF: - Robot motor factor (depends on motor specs)

Robot Efficiency

RMF is for 100% efficient systems. Gearing and friction and many other factors cause inefficiency.

General rules for estimating inefficiency – If your robot

- has external gearing, reduce efficiency 15%
- uses treads, reduce efficiency 30%
- operates on high friction terrain, reduce efficiency 10% robot efficiency becomes: -

$$\text{Efficiency} = (1 - 0.30)(1 - 0.10) = 0.63 = 63\%$$

Since our robot arm has multiple arms the following formula will be used to determine the motor requirements

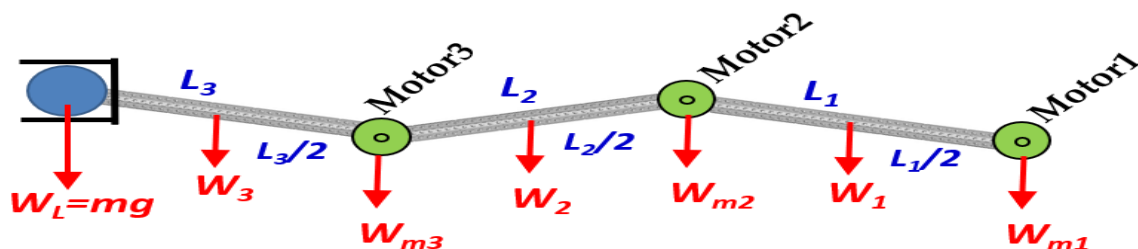


Fig 2.11 Multi robot arm load diagram (Elouafiq, 2011)

$$\tau_3 = (mg \times L_3) + (W_3 \times L_3 / 2)$$

$$\tau_2 = [mg \times (L_3 + L_2)] + [W_3 \times (L_2 + \frac{L_3}{2})] + (W_{m3} \times L_2) + (W_2 \times \frac{L_2}{2})$$

$$\tau_1 = [mg \times (L_3 + L_2 + L_1)] + [W_3 \times (L_1 + L_2 + \frac{L_3}{2})] + [W_{m3} \times (L_1 + L_2)]$$

$$+ [W_2 \times (L_1 + \frac{L_2}{2})] + (W_{m2} \times L_1) + (W_1 \times \frac{L_1}{2})$$

Depending on the above calculation motor specification will be set. On other hand the gear capacity will be determined using the following formula

$$\tau_{old} \times v_{old} = \tau_{new} \times v_{new}$$

↑

Motor specs

Unfortunately for robots, motors commercially available do not normally have a desirable speed to torque ratio (the main exception being servos and high torque motors with built in gearboxes).

Gears work on the principle of mechanical advantage. This means that by using different gear diameters, you can exchange between rotational (or translation) velocity and torque by looking at the motor datasheet you can determine the output velocity and torque of your motor. But unfortunately for robots, motors commercially available do not normally have a desirable speed to torque ratio (the main exception being servos and high torque motors with built in gearboxes). (Elouafiq, 2011)

C. Control Mechanism

The introduction of sensors in production processes leads to a progressive step towards achievement of expanded adaptability with respect to volume of production, product variation and life cycle of product. The sensors in production processes can be utilized for optimization and process control of diverse machines and different machine tools. The sensors can also be used to expand the adaptability of the robot framework and empower the utilization of robots in irregular production which leads to recognition of various issues that must be understood effectively to coordinate sensors and enhance effectiveness of the system (Amruta Rout, 2018). The control strategy for the arm requires a certain amount of data feedback. All of the joint's angles for both passive and active DOFs must be measured. In addition, the reaction forces between the manipulator and the real activity must be measured in at least as many degrees of freedom as there are kinematic degrees of freedom within the activity (Liszka, 2006).

To move the welding torch along the weld seam path, teach pendant used to be utilized in traditional robotic welding system. In addition to this, programming for setting of weld parameter, starting and extinguishing of arc and controlling of shielding gas and use of robot controller for smooth welding have to be performed simultaneously. But this often results in to error in torch positioning and unsatisfactory weld quality. These issues can be handled easily by the use of sensors for seam tracking and weld pool inspection. These issues can be handled easily by the use of sensors for seam tracking and weld pool

inspection (L.M. Sweet, 2004). Sensor integration with the robot manipulator can improve the welding process in an intelligent manner (A. Bauchspiess, 2001).

Joint findings and tracking

From seam tracking operation the maximum used sensor in industries and research works now- a-days is laser sensor and mostly for arc welding. The vision sensor is the next most used sensor for seam tracking operation in industries. The reason may be the accuracy and ease of use with laser sensor cannot be obtained by other sensors. Sensors are used in maximum range for robotic arc welding like TIG, MIG and PAW. (Amruta Rout, 2018)

As a summary these following method are some of the common sensor used to track seam in robotics welding.

- i. Arc sensor for weld seam tracking
- ii. Vision sensor for seam tracking
- iii. Laser vision sensor for seam tracking
- iv. Ultrasonic sensor for weld seam tracking
- v. Electromagnetic sensor for seam tracking
- vi. Infrared sensing for weld seam tracking
- vii. Composite sensor for weld seam tracking
- viii. Tactile sensor for weld seam tracking
- ix. Touch sensor for seam tracking
- x. Weld pool observation sensing for seam tracking
- xi. Mobile robot with seam tracking system
- xii. CAD based seam tracking

2.5. Concept design of production system

Fast and intuitive programming of robotic manufacturing systems is a main challenge to enable cost-effective automation of complex production processes in small and medium-sized enterprises (SMEs) with changing product variants and small lot sizes (Kuss, 2016). Research in this field falls into the two categories of online and offline programming (Pan, 2012). In online programming, the user typically moves the robot to desired positions using a teach pendant. Even though online programming is simple and widely used in industry, it can be time-consuming and leads to downtimes of the robot cell. Moreover, the quality of the robot process depends on the skills of the human operator. This knowledge is not modeled and cannot be reused for new product variants.

Besides the description of the manufacturing task through welding features, it is also important how to determine these features in the OLP system. There exist three main approaches: (1) Design-by-feature,

(2) feature mapping and (3) feature recognition. The Design-by-feature approach is based on including manufacturing information in the design phase of the product. (Alexander Kussa, 2017)

The representation specifies manufacturing information and product related geometric constraints relevant for automatic program planning in robotic arc welding. The geometric constraints are transformed into simple continuous curve primitives such as lines, circular arcs and B-spline curves supporting the easy integration in robot program planning systems decoupled from a complex CAD environment. It also represents information on welding gaps along the joint geometry. Moreover, a method for automatic feature recognition based on rule-based pattern recognition is presented to automatically retrieve manufacturing information from the CAD model of the product and generate the respective manufacturing task specification. The method is evaluated in several test scenarios for welding product assemblies indicating the usability and effectiveness for automatic program planning in robotic welding (Alexander Kussa, 2017). In order to improve the manufacturing productivity and the movement stability, trajectories with short execution time or smooth profile are highly desired. Many time-optimal techniques have been investigated in the past decades, such as dynamic programming techniques (K. Shin, 1986) and phase plane methods (J.E. Bobrow, 1985). In the manufacturing process with industrial manipulators, motion movements are usually required to be executed in a time-jerk optimal manner. It is expected that the trajectory is smooth enough to avoid overlarge mechanical vibration, and costs traveling time as less as possible to improve the productivity with applying kinematic constraints at the same time. The kinematic constraints include the limits of angular velocity, acceleration, and jerk which provides an indirect way to make the profiles of the actuator torques smooth.

2.5.1. Material choice

The material of the frame that is used must meet the same requirements as those for the arm. It should be light weight while remaining stiff so that the position of the arm can be precisely controlled. Also, it should be easily mountable and produced and relatively inexpensive. In this selection aluminum will be best fit for different arm types. The engineering aim is a design proposal with maximum stiffness and minimum weight for a given set of loads. For topology optimization and FE modeling may be used to minimize the volume of the design space while not violating the maximum deflection at specific point (H. Hagenah, 2013) . Robots are mostly built of common materials. Some specialized robots for clean room applications, the space program, or other "high tech" projects they may use titanium metal and structural composites of carbon fibers.

2.5.2. Transmissions

For some links a transmission is necessary to reach the desired torque. The desired torque varies with the weight. The first assumption for the weight of the robot arm was based on the mass distribution of the robot. At this moment a second assumption can be made with use of the weight of the arm.

2.6. Robot arm controller

Conventionally robot arm is controlled using reprogrammable path given from different sources. In this method the main drawback is setting the torch to follow welding line or welding seam. This problem happened depending of two main reasons. I.e. difficulty in 3D space line positioning and material deflection due to heat generated and electric from the weld which leads to a change in welding line and weld gap during welding processes which, highly affect welding qualities. Not only this, other real time welding parameters also complicated to regulate. For numbers of years, there has been intensive effort are done to develop automatic real time parameters control system for different welding process for purpose of tracking and weld seam quality. Now a day's different sensors are developed to overcome the snags. There direct and indirect types of tracking system of weld are on the industry. The direct sensors type senses directly the weld joints. These, are thermal, mechanical, image (vision), optical, and electrical sensor can be mentioned. These sensors measure metal surface geometry, weld path, weld gap, material thickness change and the like. The indirect sensing mechanism is sensing through inference effect from the arcs as the gap between the work piece and torch increases the arc voltage varies in a predictable manner. Hence, this changes in the arc voltage will be used to maintain the arc gap. Still a number of sensors are not compatible with welding seam path with two and more. (A. Bauchspiess, 2001)

The computer control unit for robot has memory in which welding plant setting and instruction on sequencing and on the path, it must follow are stored. A series of control buttons are arranged in a programming unit sometimes called a teach pendant, which controls and may be held in the operator's hand. A system of teaching by showing in which the torch or a stylus replacing it is moved through the desired trajectory can be employed in same robots. This trajectory will be stored in memory reproduce in demands. Usually programming is carried out by dividing by the robot to a series of points along the desired path using push button on the touch pendant. By using different button, the end effector will be showed different points and recorded on the memory. The control software enables the robot to interpolate too the stored points to a continuous trajectory for the weld seam to be followed. Joystick can also be used for speed up of point location. This stored path will be recalled whenever necessary. (A. Bauchspiess, 2001)

2.7. Welding end-effector and welding process controller (Leutenegger, 2008-10)

The end effector is probably one of the most important and most complex parts of the system. The end effector varies mainly according to the application and the task that the robot arm accomplishes for; it can be pneumatic, electric or hydraulic. The mechanical design needs to comply with several constraints, such as the lacking DOF, or the weight limit. Conclusion of this first step necessitates some driver software development and integration of hardware and software with the arm as well. The major challenge faced in end effector design is caused by the trade-off between their complexity (including number of DOF) and flexibility with respect to the range of objects that may be grasped. Industrial robots tend to be equipped with highly specific but comparably simple tools (that may be exchangeable) such as 1-DoF grippers. Human hand resembling end effectors, however, are examples of the complex end of the end effector spectrum: their design complexness also imposes major challenges in terms of control. Having selected the rotation symmetric Gripper design, the actuator is constrained to be linear. The selection criteria of the linear motor mainly consisted of cost, weight, and controllability. Most linear actuators are worm-gear electric motors. Solenoids were not considered as an alternative due to their three issues: comparably low exerted forces, highly varying force/velocity profiles, and very high-power consumption in the ON-state. While the total amount of linear actuators available is enormous, it is not easy to find miniature linear actuators.

There are of different divisions of end effector like. Impactive, Ingressive, Astrictive, Contigutive. These works differently for different end effectors.

- **Impactive:** - This works as a jaw or fingernail that grasp physically by giving an explicit collision to the object that is to be acted.
- **Ingressive:** - Use of pins, needles that helps in physically infiltrating the surface of the object.
- **Astrictive:** - It is nothing but the suction that is generated on the surface of the object, which is produced through vacuum cups as outsource and by electromagnetic stuff if in use.
- **Contigutive:** - It is enforced to have a direct contact for the holding process of the object, for example surface tension generated at particular point. So, these are the categories based on various physical belongings of the system. And in individual purpose depending on the working material like for metal sheets, vacuum cups or electromagnets play a dominant role as end effectors (Gururdu Rishank Reddy, 2016).

2.8. Software requirements design for robotics arm

2.8.1. User interface and analysis software

In the motion study of the robot, direct and invert kinematics and dynamics' equations were solved utilizing MATLAB, Ansys, Simufact, Simulink or other software, and the results of this solution will be

utilized for simulating the robot. The outcomes of this simulation were the diagrams of angles, velocities, and accelerations of all the arms, and the applied force and torque of each arm required for drive the mechanism. The above mentioned software's are specifically to analyses the movements of the arm and the welding parameters and quality. On the other hand, the software required to drive the arm. This driving software can be coded using different coding software depending on their application. As an example, for educational purpose se we can use software easier to code but less strength and for operation purpose sophisticated software coding can be implemented for higher security of the job to be done. Some of the software used in education purposes are Arduino. Ide, python, MATLAB. For operation case java, C++ and other software can be used. (A. Emami, December 2011). As a user interface software CAD/CAM, MATLAB, and other software can be mentioned.

2.8.2. Teaching Software

Different methods exist for teaching or programming a robot controller; namely, manual methods, online programming (walk-through, lead-through), and offline programming. Manual methods are primarily used for pick-and-place robots and are not used for arc welding robots (Cary, 2005). Online programming this category of robotic programming includes lead-through and walk-through programming. Use of the manual online programming method requires no special hardware or software on-site other than that which is used for the manufacturing process. The major drawback of online programming is that it is quite inflexible and it is only able to control simple robot paths (Pan Z, 2012).

In the walk-through method, the operator moves the torch manually through the desired sequence of movements, which are recorded into the memory for playback during welding. The walk-through method was adopted in a few early welding robots but did not gain widespread use (Cary, 2005).

The conventional method for programming welding robots is online programming with the help of a teach pendant, i.e., lead-through programming. In this approach, the programmer jogs the robot to the desired position with the use of control keys on the teaching pendant and the desired position and sequence of motions are recorded. The main disadvantage of the online teaching method is that the programming of the robot causes breaks in production during the programming phase (McWhirter, 24 January 2012.).

The teach and playback mode has limited flexibility as it is unable to adapt to the many problems that might be encountered in the welding operation, for example, errors in pre-machining and fitting of the workpiece, and in process thermal distortion leading to change in gap size. Thus, advanced applications of robotic welding require an automatic control system that can adapt and adjust the welding parameters and motion of the welding robots developed (Hongyuan, 2009). A closed loop control system for robots that used teach and playback based on real-time vision sensing for sensing topside width of the weld pool

and seam gap to control weld formation in gas tungsten arc welding with gap variation in multi-pass welding. In spite of all the above mentioned drawbacks, online programming is still the only programming choice for most small to median enterprises (SMEs). Online programming methods using more intuitive human-machine interfaces (HMI) and sensors information have been proposed by several institutions (Zhang, H, Chen, H, Xi, N, Zhang, G, He, J, 2006). The assisted online programming can be categorized into assisted online programming and sensor-guided online programming. Although dramatic progress has been carried out to make online programming more intuitive, less reliant on operator skill, and more automatic, most of the research outcomes are not commercially available aside from (Sugita, S, Itaya, T, & Takeuchi, Y, 2003).

Offline programming (OLP) with simulation software allows programming of the welding path and operation sequence from a computer rather than from the robot itself. 3D CAD models of the workpiece, robots, and fixtures used in the cell are required for OLP. The simulation software matches these 3D CAD models, permitting programming of the robot's welding trajectory from a computer instead of a teaching pendant in the welding cell as in online programming. After simulation and testing of the program, the instructions can be exported from the computer to the robot controller via an Ethernet communication network. Ongoing research suggests, however, that the use of sensing technology would make it feasible to completely program the final trajectory only with OLP. developed an automated offline programming method with software that allows automatic planning and programming (with CAD models as input) for a robotic welding system with high degrees of freedom without any programming effort. (Miller Electric Mfg Co, 2013) . The main advantages of OLP are its reusable code, flexibility for modification, ability to generate complex paths, and reduction in production downtime in the programming phase for setup of a new part. Nevertheless, OLP is mostly used to generate complex robot paths for large production volumes because the time and cost required to generate code for complex robotic systems is similar to if not greater than with online programming (Pan Z, 2012). Currently, for a complex manufacturing process with small to median production volume, very few robotic automation solution are used to replace manual production due to this expensive and time-consuming programming overhead. Although OLP has the above mentioned advantages, it is not popular for small to median enterprise (SME) users due to its obvious drawbacks. It is difficult to economically justify an OLP for smaller product values due to the high cost of the OLP package and programming overhead required to customize the software for specific application. Development of customized software for offline programming is time-consuming and requires high-level programming skills. Typically, these skills are not available from the process engineers and operators who often perform the robot programming in-

process today. As OLP methods rely accurate modeling of the robot and work cell, additional calibration procedures using extra sensors are in many cases inevitable to meet requirements (Pan Z, 2012).

Intelligent robot it is very difficult and even impossible to anticipate and identify all situations that the robot could do during his task execution. Therefore, the software developer must specify the categories of situation and provide the robot with sufficient intelligence and the ability to solve problems of any class of its program. Sometimes, when situations are ambiguous and uncertain, the robot must be able to evaluate different possible actions. If the robot's environment does not change, the robot is given a model of its environment so that it can predict the outcome of his actions. But if the environment changes, the robot should learn. This is among other prerequisites, which calls for the development and embedding in robots' system of artificial intelligence (AI) capable of learning, reasoning, and problem solving (Tzafestas, 1995).

The most welding robots serving in practical production still are the teaching and playback type and cannot well meet quality and diversification requirements of welding production because these types of robots do not have the automatic functions to adapt circumstance changes and uncertain disturbances (errors of pre-machining and fitting workpiece, heat conduction, dispersion during welding process) during welding process (Tarn, 2004).

2.9. Part positioner and robot positioner

Majorly the robot arm can access area limited to its arm which most robot can reach around 2m diameter. A robot can be useful in large area if additional fixtures are imbedded together for a suitable work progress. The fixtures move the workpiece in top the working area of the robot and moves the work continuously place it on suitable location for the robot if required. Some of the fixture can be imbedded in robot manipulators are gantry system, movable work bench and rail system and other types of fixture can be used to extend the working area. (Dinham, 2013)

2.10. Operator support

At the early stages of the automation operators have to programs using the teach pendant to follow a nominal path along the weld joints. The operators also show the robot the desired weld nominal weld parameters like weld speed, arc current, wire feed rate, time of arc ignitions. With the use of sensors and automation technology currently the robot can sense the welding parameters listed above therefore the main purpose of the operators are to teach the robot the welding quality parameters i.e. seam width, depth of penetration, in advance instead of showing the loop of welding conditions. (Dinham, 2013)

2.11. Efficient user interface

A series of research are undertaken using CAD system to use as user interface between robots and operators. As an example, a review on CAD-based robots path planning for spray painting is presented.

(Cheng H., 2009) (Negata F., 2007) Proposed a robotic sanding platform where the robots' path is generated by CAD/CAM software. There is also different user interface system. In developing of user-friendly interface, the following seven steps are mentioned by (Donghong Ding, 2015). The seven steps from loading STL model to generate the robotic codes are: -

Step1. Load STL model: – input 3D digital STL file

Step 2. Bead modelling: - it is trained using the artificial neural network (ANN) and the bead database will be saved for the next step.

Step 3. Slicing: - 3D STL model will be sliced to 2D

Step 4. Path planning: - MAT based paths are automatically generated with appropriate step

Step 5. Weld Setting: – feed rat, travel speed, and stick out length are selected from the automatic generated data

Step 6. Post Process machining: - Machining paths are also automatically generated

Step 7. Robot code generate: - An integrated file with robot is generated.

2.12. Implementation methodology

2.12.1. Data acquisition

The data for any path to be welded can be directly acquired from cad drawing through Autodesk Inventor. Each CAD model consists of in a robotic cell point and poses. The data acquired from CAD model are transformation matrices consist of rotating, mirroring, scaling and the like.

2.12.2. Data processing (Nuno Mendes, 2013)

In data processing the first step is information processing and data discretization. When discretization a robot path, two important factors should be taken in to consideration

- The movement types
- The orientation assumed by the robot during performing the movement

Different discretization process is developed in the robot path identification process

- Linear discretization:** - Used for any linear path. During linear interpolation, the TCP travels along a straight line between the start and destination points. To obtain a linear path in the object coordinate system, the robot axes must follow a nonlinear path in the axis space. The more non-linear the configuration of the robot is, the more accelerations and decelerations are required to make the tool move in a straight line and to obtain the desired tool orientation. (P. Surenderath, 2015)
- Circular discretization:** - used for circular path. Circular interpolation: The trajectory circular interpolation is used for tool motion as well as for interpolation near the intermediate via points of nonlinear trajectory. A circular path is defined using three programmed positions that define a circle segment. The first point to be programmed is the start of the circle segment. The next point is a

support point (circle point) used to define the curvature of the circle, and the third point denotes the end of the circle (P. Surenderath, 2015).

- iii. **Curvature discretization:** - it is used for effective computation method for most engineering problems. The main idea behind this parameters surface discretization is the quadratic of the curve segment from the position and normal vector at the end point (Boschiroli M., 2011).
- iv. **Orientation interpolation:** - this method is very efficient and reliable for different kinds of robot application. The orientation increment is linear.
- v. **B-spline interpolation:** - B-spline interpolation technique allows constraints to be imposed on the magnitudes of the joint velocity and acceleration as well as on the initial and final values. Additionally, the jerk constraint and the jerk continuity are guaranteed, resulting in the trajectory smoothness (Jusen Huang, 2017).
- vi. **Joint interpolation:** - When the accuracy of the path is not too important, this type of motion is used to move the tool quickly from one position to another. Joint interpolation also allows an axis to move from any location to another within its working space in a single movement. All axes move from the start point to the destination point at constant axis velocity.

Many of robot are not able to easily interpolate sensor feedback. Therefore, additional care needs to be taken to ensure proper running of the system. One of the possible approached is to discretize the path in small paths (Negata F., 2007). Some appropriate adjustment should be done on those small paths which the robot is performing them. Several studies are undertaken which presents CAD/CAM based position/force controller. (Nagata F., 2007) The study addresses a calculation method of robot orientation from cutter location data. Some algorisms for robot path discretization have proposed to smooth robot paths (position and orientation) (Feng Yun L., 2005). (G., 2004) Proposed an algorithm for nonlinear smooth interpolating orientation which should excellent result when used in spline curve. (Sheng W., 2001) Presents a method for robot path planning where nominal data extracted from a CAD surface

2.12.3. Operation process

If we want the robotic device to undertake a given task, important to control it and it should also possess the capability of sending specific orders to the manipulator which has to be carried out in terms of positions or velocities of its final effectors (R.B. Gillespie, 2001). Secondly, it should be able to sense the real obtained position or velocity. Capabilities that may be pivotal depending on the application. Therefore, in order to implement a control algorithm for the manipulator to solve a particular task, it is mandatory to control its basic functions which include moving and which further leads to the development of a software (Kumar, 2002). Basically, a robotic manipulator and sensors manufacturers

provides a set of functions low level features of robots and sensors are needed to be integrated within the full software applications which are then used to solve particular task.

The manufacturing task description is based on welding features. Unlike in machining where a feature is composed of different elements of the CAD model, the geometric elements of a welding feature are typically not modeled in the 3D CAD model during the design phase. Instead, information about welds is given in the 2D drawing of the product with references to the product geometry and is interpreted by the human process experts in the production process. Hence, a machine-readable description of a weld feature represents additional information to an incomplete CAD model. It has to define constraints for the robot motion along the workpiece. The transformation of the motion constraints to a tool frame position of the robot welding gun can be performed by a subsequent process planning with a robot offline planning system but is not focus of this work. A weld feature includes information on the joint geometry and the seam geometry. (Alexander Kussa, 2017)

2.13. Problems in robotic welding

Despite the benefits from using robotic systems, associated problems require due consideration. Issues include the following: The consistency required for making part after part, which, in the absence of proper control, might fluctuate due to poor fixturing or variations in the metal forming process. In the case of low to medium volume manufacturing or repair work, the time and effort taken to program the robot to weld a new part can be quite high (Dinham, 2013). Robotic welding requires proper joint design, consistent gap conditions and gap tolerance not exceeding 0.5 to 1 mm. Variation in gap condition requires the use of sensing technologies for gap filling (Robot Welding, 4 September 2013).

Automation of welding by robotic systems has high initial cost, so accurate calculation of return on investment (ROI) is essential. Possible shortages of skilled welders with the requisite knowledge and training pose limitations.

2.14. Automation

2.14.1. Robotic configurations

Robots can be categorized based on criteria like degrees of freedom, kinematics structure, drive technology, workspace geometry, and motion characteristics (Tsai 2000). In selection of robots for a specific application, all of these factors need to be considered. Based on the workspace geometry, robots with revolute (or jointed arm) configuration are the most commonly used type in industrial robotic arc welding (Ross et al. 2010). Figure 2.12 illustrates an example of a revolute configuration robot.

2.14.2. Phases in welding operations

The welding operation consists of three different phases that need critical consideration in designing a fully automated robotic welding system to achieve good performance and weld quality (Pires et al. 2006)

Preparation phase:- In this phase, the weld operator sets up the parts to be welded, the apparatus (power source, robot, robot program, etc.) and the weld parameters, along with the type of gas and electrode wires. When CAD/CAM or other offline programming is used, a robot welding pre-program is available and placed online. Consequently, the robotic program might only need minor tuning for calibration, which can be easily done by the weld operator performing selected online simulations of the process.

Welding phase Automatic equipment requires the same capabilities as manual welding, i.e., the system should be capable of maintaining a torch orientation that follows the desired trajectory (which may be different from planned), performing seam tracking, and changing weld parameters in real time, thus emulating the adaptive behavior of manual welders.

Analysis phase: - The analysis phase is generally a post welding phase where the welding operator examines the obtained weld to ascertain if it is acceptable or whether changes are required in the previous two phases. Use of advanced sensors, such as 3D laser cameras, enables execution of this phase online during the welding phase (Cary, 2005)

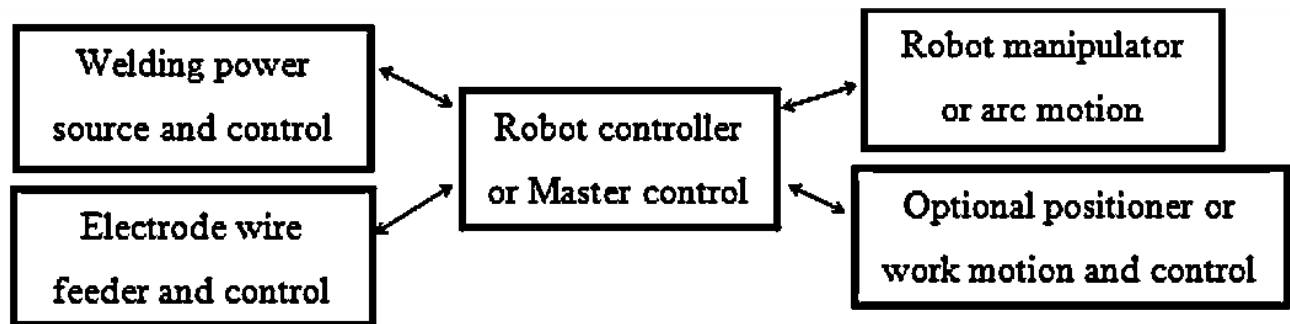


Figure 2.12 Robotic arc welding system (Cary, 2005)

Chapter 3: Design of Robotic Arm for Arc Welding

3. Design Background

Understanding design process, fabrication, specifying standard products and collecting from market, assembling, and control system for robot automation in MIG/TIG welding was the primary goals of this thesis. In this project, the control system refers to the construction of a mechanism which controls automatic movements of the mechanical arm to the intended position with a predetermined accuracy. This thesis includes various aspects of engineering concepts; mechanizations (control system), forms of electronic drives, parts design (FEM analysis) and mathematics and so on. The outcome is that, this thesis supports to develop the skills of theoretical and practical knowledge concerning the real life.

3.1. Introduction

In order to construct a capable robotic arm to perform the intended tasks accurately and efficiently, proper design and simulation are deemed necessary. In this chapter, the design procedure and calculations were presented for the six DOF robotic arm shown in Fig. 3.1. The use of a robotic arm is to weld steel of thickness ranges 2mm to 10mm using MIG/TIG welding process. The forward and inverse kinematics of the six DOF robotic arm was established. The later, the inverse kinematics, determines the joint angles required to reach the desired position and orientation of the end effector. Furthermore, the static torques, the most appropriate link cross sections, and the workspace were determined.

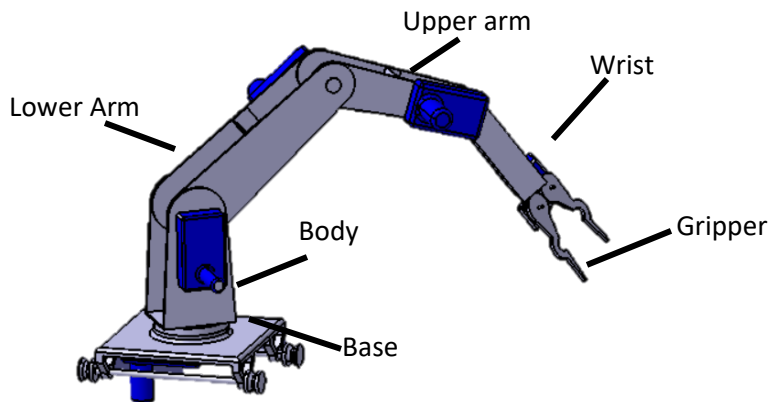


Figure 3.1 A 3D Catia model of six DoF robotic arm

3.2. Conceptual Design

3.2.1. Concept design

In designing the mechanical arm, the following steps are followed

1. Identified different components of the arm from different literatures and listed in detail

2. Searched standard components for their availability and costs from the market with respect to their specification to conform the intended function
3. Determined their specification and start detail design, material selection, modeling and FEM analysis
4. Fabricate parts
5. Assembled
6. Configured with the software
7. Tested

3.2.2. Concept design tree

Before starting the overall design process a well-defined conceptualization is necessary. The main points to be addressed are reliability, resource availability, functionality, safety, affordability, manufacturability, and other critical consideration to addressed in succeeding the project as well as its usefulness in future robotics development. The overall process parameters conceptualized in this thesis work are shown in Fig. 3.2. In this stage, a clear road maps of welding type, material to be welded, area to be covered, resource availability and some basic design parameters are identified as mentioned in section 3.6.

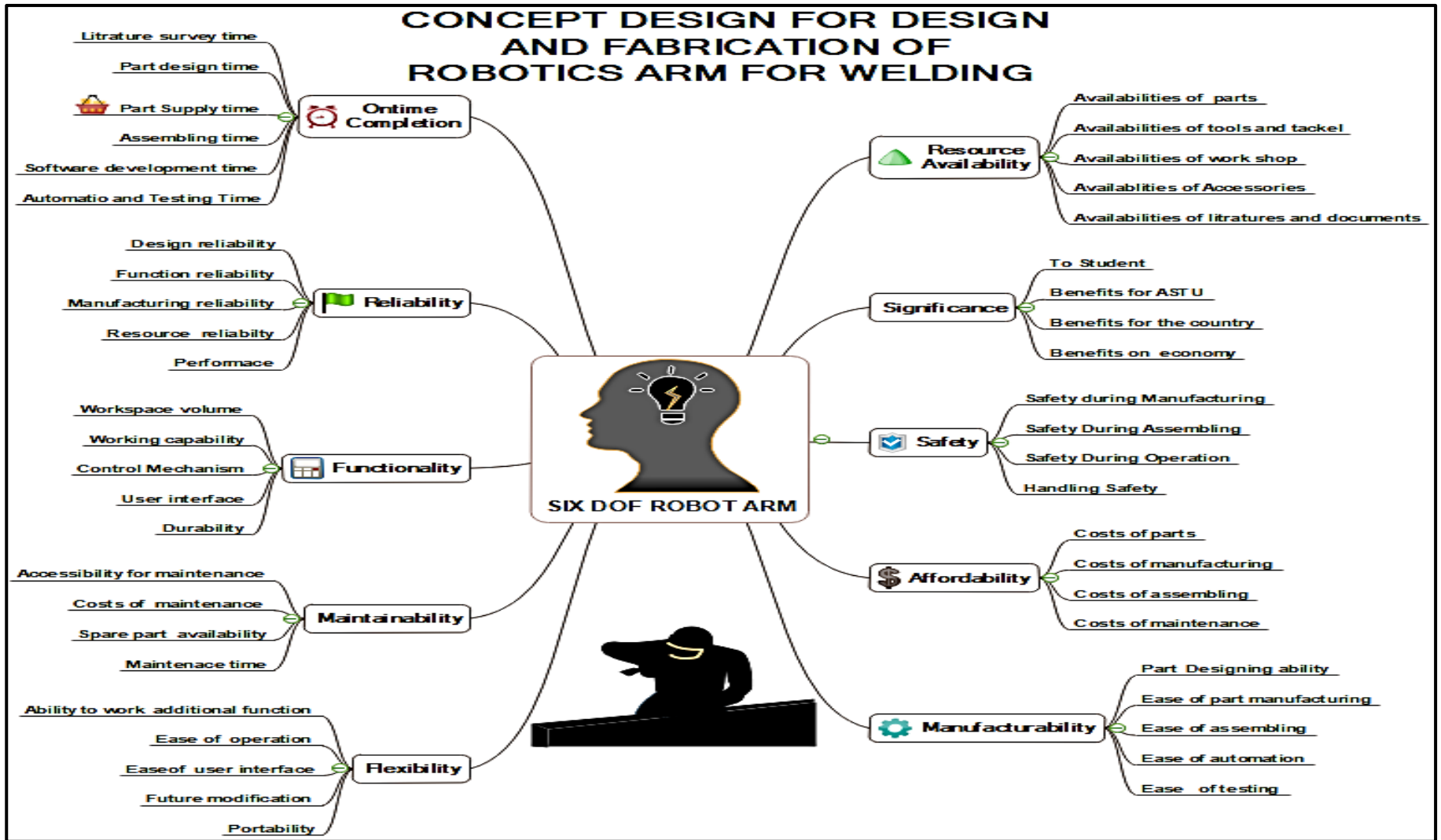


Fig 3.2 Schematic Concept Design objectives tree

3.3. Section Modulus

In order to determine the most appropriate cross-sectional shape of the robotic arm's links, three possible geometries were considered; a solid cylindrical beam, a hollow cylindrical beam and a set of two rectangular beams. The section modulus, S , is a geometrical property, which indicates the strength of beams based on their cross-sectional shapes or areas.

$$S = \frac{I}{c}$$

Where, I is the second moment of area (mm^4), and c is the maximum distance from the neutral axis (mm).

It can be seen from the generated graph, shown in Fig. 3.3 that for any value of the cross-sectional area, the set of two parallel rectangular beams has the highest value of S , followed by the hollow cylindrical beam and then lastly, the solid cylindrical beam. This means that the set of two parallel rectangular beams have the highest structural strength to weight ratio out of the three links, considering they are all made of the same material. Hence, rectangular beams were used for the robotic arm's links.

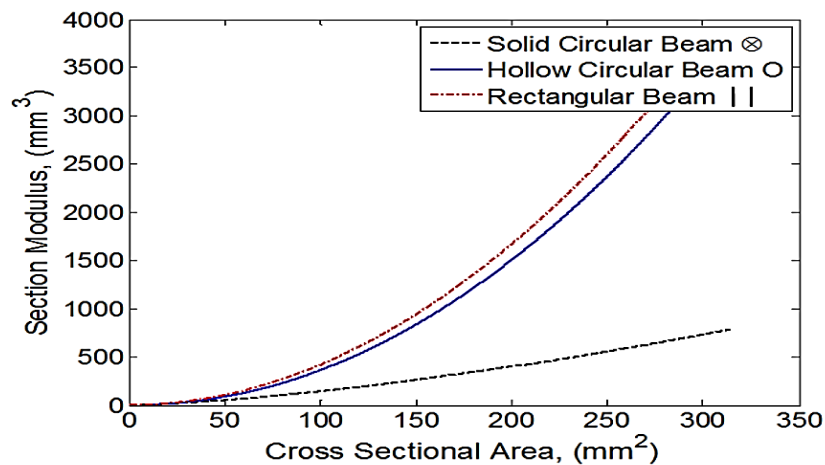


Figure 3.3 The section modulus against cross sectional area for the three considered beams (Madiha Farman, April 2018)

3.4. Preliminary data acquisition

In this process the first step is determining the intended work to be done by the robot arm they are; i) welding type to be done, ii), weight of working torch, iii) welding length, iv) material to be welded, v) working space to be covered, vi) welding position, and other parameters. After determining the above stated factors alternative method are available to determine other information's. In this section, an online software is used to define preliminary data of the arm. The primary data retrieved from an online software and the input used are shown below.

3.4.1. Robot Arm Calculator

This online Robot arm calculator is designed to determine the lifting capability of robot arm. For example, can a robot arm of X length, with M motor, lift Y weight? The following data are the primary data retrieved from online arm calculator for further design and data analysis (Fig. 3.4). This method is used only to create an approximate length of each arm depending on the possible motor available in market using try and error. Further detail design analysis will be done later to make the design feasible and arrange parts accordingly. The data shown on the table starting from 3.1 to 3.6 are the most possible arrangement to be feasible on the actual design.

3.4.1.1. Input data

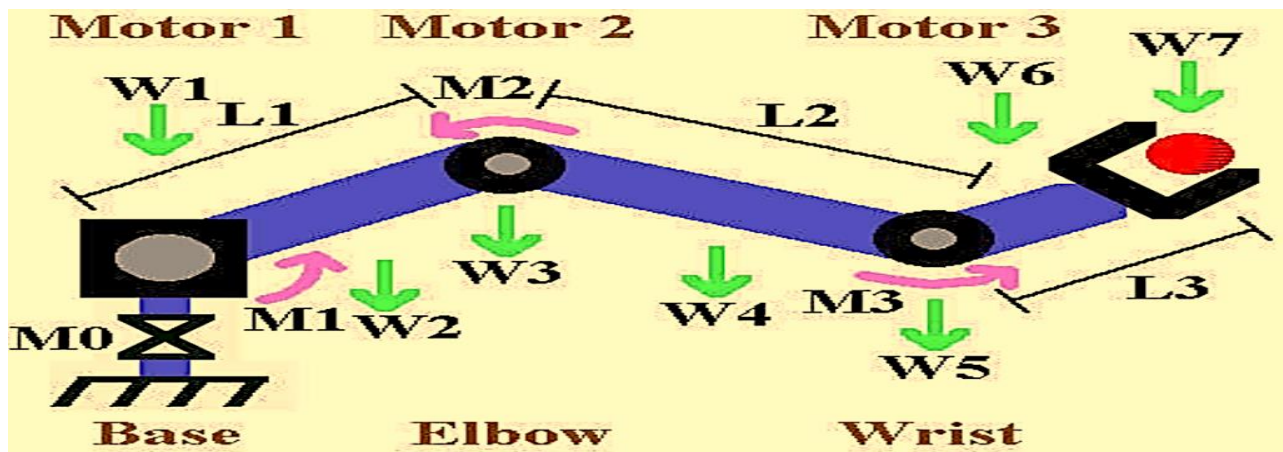


Fig 3.4. Load diagram of robotics arm

Arm Lengths

Between each motor joint is an arm linkage L. Enter the length of each linkage. If a linkage does not exist set L to zero.

Table 3.1 Preliminary arm length data

Select inches or meters	meters ▼
L1	.30
L2	0.20
L3	0.15

Arm Weight

Now enter the weight of each arm linkage. The center of mass is assumed to be 1/2 of L. If a linkage does not exist, set the weight to zero.

Table 3.2 Preliminary arm weight data

Select pounds or kilograms		kilograms ▼
W2	0.41	W4 0.27
W6	.21	W7 (object weight) 1.55

Motor Weight

Enter in the weight of each motor. Motor 1 is the base motor, Motor 2 is the middle joint, and Motor 3 is the wrist motor.

Table 3.3 Preliminary motor weight data

Select pounds or kilograms	kilograms ▼
Base Motor M1	0.68
Joint Motor M2	0.68
Wrist Motor M3	0.68

Joint Rotational Acceleration

Table 3.4 Preliminary speed data

V0	30	degrees/s ²
V1	30	degrees/s ²
V2	30	degrees/s ²
V3	30	degrees/s ²

For each joint to rotate at a specific acceleration, additional torque to what required is just for static lifting.

Motor Efficiencies

Motors and gearing are never 100% efficient, hence during determining the motor capacity efficiency of the system consideration need to be taken.

3.4.1.2. Output data

Torque Results

This is the maximum torque that each motor requires to lift both the arm and the given object weight at full extension at required velocity. Shorter arms and lower weights reduce required torque.

Table 3.5 Preliminary motor torque calculated

Select Units	newton*meter ▼
Motor 0 Torque M0	204
Motor 1 Torque M1	224
Motor 2 Torque M2	61.2
Motor 3 Torque M3	10.8

3.4.1.3. Miscellaneous Results

These results is useful information to help other parts of robot design. For the encoder calculation, this give the expected typical positioning error due to the base motor encoder. If a servo for the base motor, enter 360. Shorter arms and higher resolutions decrease error.

Table 3.6 Preliminary lifting weight at gripper

Total Weight	4.48		kg ▼
Enter Base Motor Encoder Res.	360	Output Arm Accuracy (inches)	0.447

From the above preliminary design main input data for the robot arm can be decided. The robotics arm main dimensions are recovered from the CAD modelling. In this model main dimensioned are determined depending on the intended function the robot arms are developed. Below some common indication to be considered are listed as follow

1. Robotics arm intended function is MIG/TIG welding
2. Material to be welded Steel
3. Pay load 1.55kg (torch and cable load)
4. Length to be welded 100mm to 150mm
5. Maximum thickness of material to be welded 10mm
6. Minimum thickness of material to be welded 2mm
7. Seam tracking mechanism mechanical tracking (rail guide)
8. Control mechanism i. Analog potentiometer, Bluetooth module, computer (open source, closed source)
9. Microcontroller used Arduino UNO/Mega 2560
10. Mechanical arm to be fabricated and assembled
11. Mechanical arm material type aluminum,
12. Cross section of arm rectangular and framed
13. Electrical part will be standard from market and assembled

3.5. The working principle

The robot will be ordered to move by any of three means mentioned above. First the robot arm directed to pick the electrode holder and then ordered to move the holder to the specific point needed to be welded the power will be on and welding starts. As the welding starts the robot will move straight line by its four wheels with welding speed controlled by a potentiometer. Overall set up are seen on Fig 3.5.

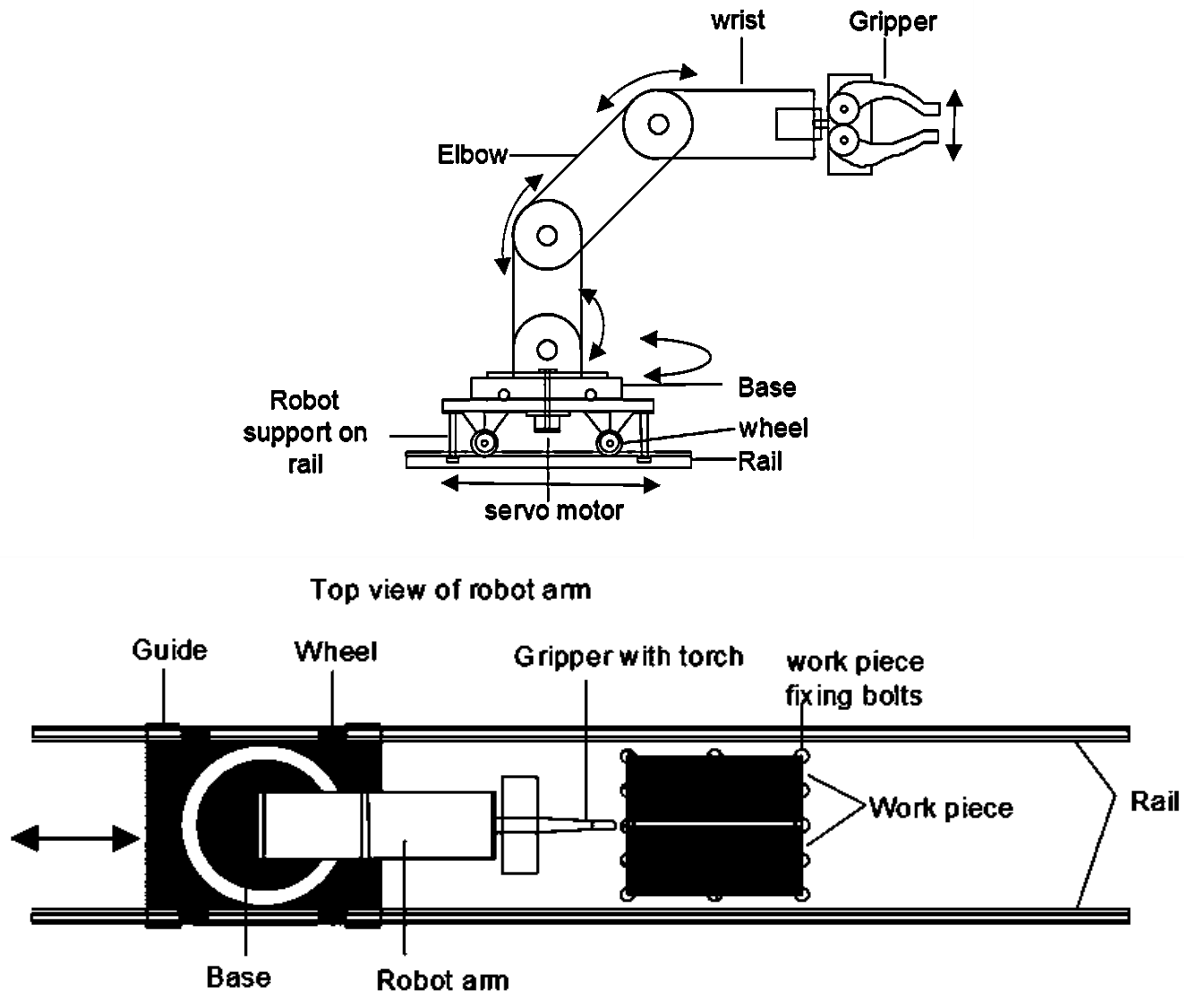


Figure 3.5. 2D CAD model of robotic arm setup

As the arm moves to its welding position the motor which drives the wheel on the rail starts to move with same amount of welding speed. The weld gap will be controlled with one of the options given in section 3.9.

3.6. Robot Workspace and Kinematics design

3.6.1. Robot work Space

The robot workspace (sometimes known as reachable space) is the place where the end effector (gripper) can reach. The workspace is dependent on the DOF, angle/translation limitations, the arm link lengths,

the angle at which something must be picked up at, etc. The workspace is highly dependent on the configuration of the robot. Since there are many possible configurations for this robotic arm. Assume that all joints rotate a maximum of 270 degrees. To determine the workspace, needs to trace all locations that the end effector can reach as in the image.

3.6.1.1. Translational envelopes:

1. Moving forward and backward on the X-axis (Surge)
2. Moving left and right on the Y-axis (Sway)
3. Moving up and down on the Z-axis (Heave)

3.6.1.2. Rotational envelopes:

1. Tilting side to side on the X-axis (Roll)
2. Tilting forward and backward on the Y-axis (Pitch)
3. Turning left and right on the Z-axis (Yaw)

The main mechanical parts of the robot will be fabricated locally and electrical parts and controlling part will be purchased and assembled locally.

The robot arm there are mainly two areas to be clearly specified

1. Maximum reachable area
2. Maximum working space

The following diagram is generated for 2m length of rail when represented graphically.

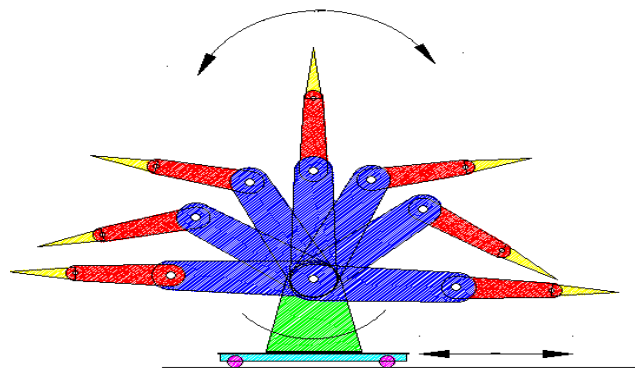


Figure 3.6 a. Robot arm movement view

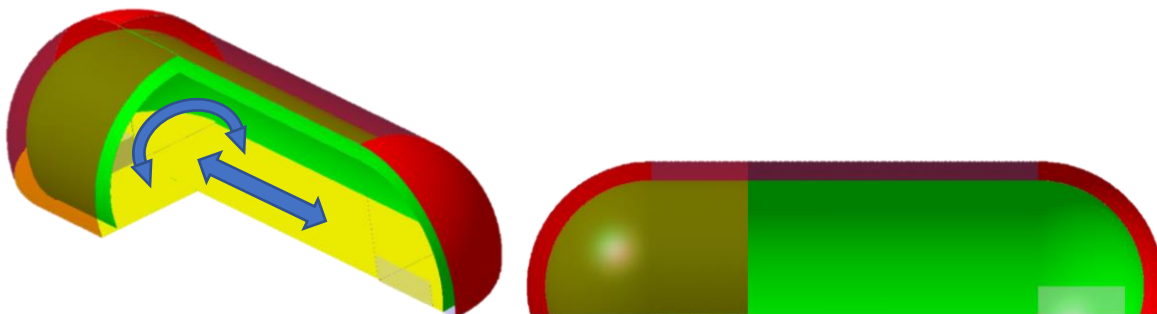


Figure 3.6 b. Diagrammatical view of maximum working and reachable area of the robot arm

From Fig. 3.6b the red and transparent red is the maximum reachable space of the robot arm, where the green is the maximum working area of the robot arm. Since the length of the rail is 1m a total of 1.90m maximum reachable length and 1m of maximum working length with 0.6m radius are built for welding automation in this thesis.

From a CAD modeling the following data was retrieved as indicated below

Length of arm-1: 20cm; Length of arm-2: 30cm; Length of arm-3: 35cm; Length of rail:100cm

3.6.2. Kinematics Design

Kinematics is a method of modeling robot motion without considering the force applied to move the robot. Kinematics analysis is divided into forward and inverse kinematics. By applying kinematics modeling, the robot design can be efficient by considering how the robot moves in x, y, and z-axis. The arm robot considered in this study is shown in **Figure 3.7 and Figure 8 below.**

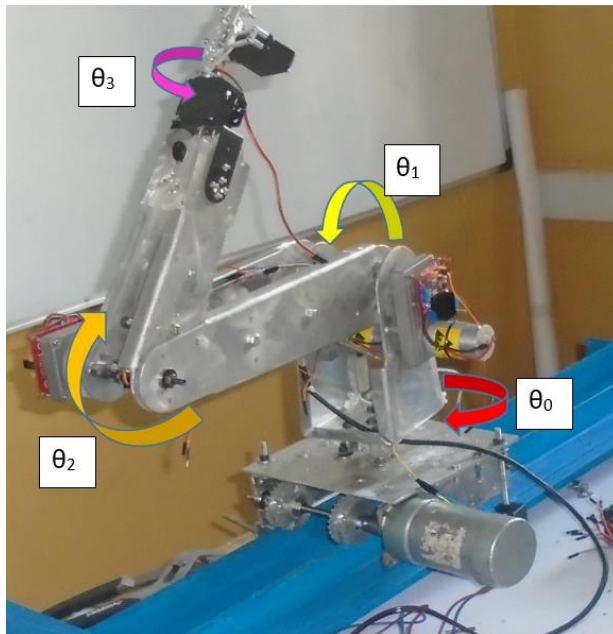


Figure 3.7. Actual fig representation of robot joints

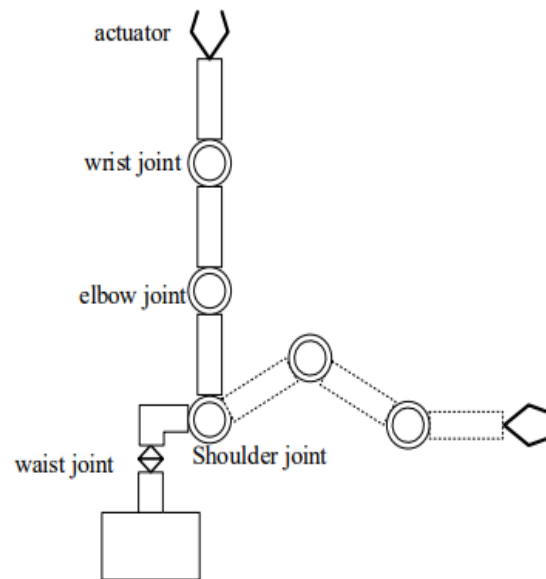


Figure 3.8 The structure of the

manipulator

(Dewi, October, 2019)

The main aim of the kinematics design is to locate the point at the desired position and perform the intended functions. Before proceeding to the design part let's set some standard value and assumptions on the movements of the arm. The overall basic variables during the movements of the arm are shown as below figure 3.9 graphical representation the arm and figure 3.10 which shows the orientation of the axes as the arm starts to move across its joint with different angle. (Bao Guangbing, 2017)

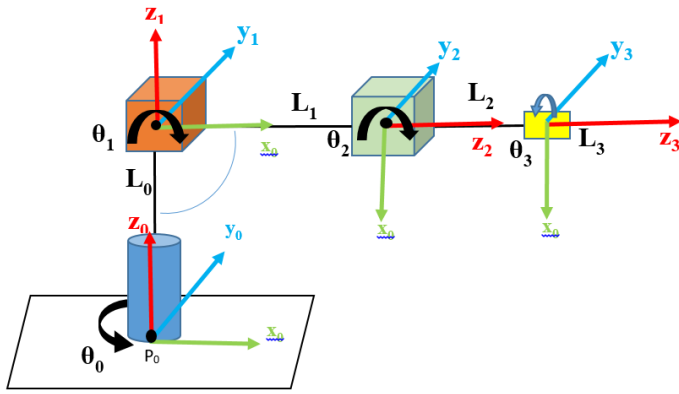


Figure 3.9: - Graphical Representation of the Variables and point in space

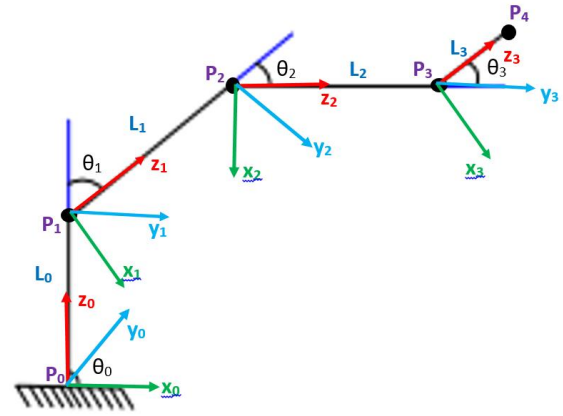


Figure 3.10 Diagrammatical representation of the variables on joints

NB:-

If motions are presented with cylindrical or circle geometry the rotation is 360° revolute and motion represented with rectangular geometry are the movements of the arm are 270° max and perpendicular to the corresponding revolute motion of the arm. The joint configuration are show on figure 3.11 below

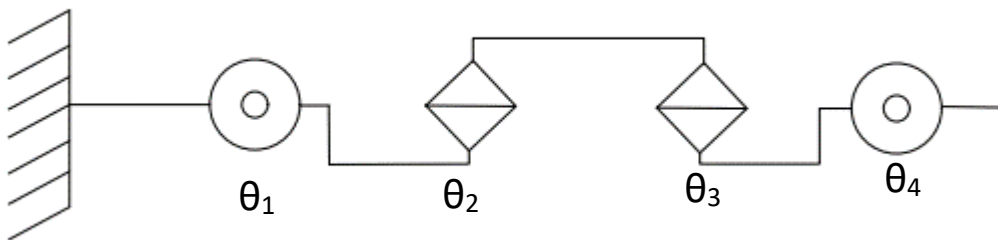


Figure 3.11 Joint Configurations

Assumption

The travers motion the robot are not shown here because the arm rail main function is to orient the end effector during real time welding operation. Hence the manual kinematics is done on the mail four joints which uses to locate the end effector position.

The variables and other kinematics parameters used in this paper are define as follow:-

- θ_i is the angle (that has a sign according to the right-hand rule) between the x-axis and shows how much we rotate the x-axis of the previous joint around z-axis in order that the x-axes have the same direction;
- P_i is respective origin points of the joints
- $x_i, y_i,$ and z_i are the point in space the respective joints exists
- α_i is the angle between the z-axes and the amount of rotation around x-axis.
- d_i is the distance on the x-axis between the two common normal;
- a_i is the length of each common normal (so called joint offset);

Note that the parameters a and α are always constant, while θ is a variable if the observed joint is revolute and d is variable if the joint is prismatic

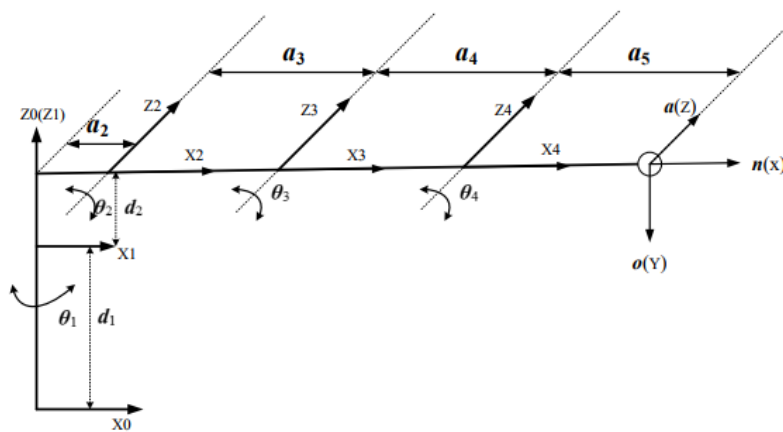
Table 3.7 Summary of DH parameter (Dewi, October, 2019)

Parameter	Symbol	Description	Variable/Constant	Relation
Joint angle	θ_i	Rotation about z-axis	Variable	Joint
Link offset	d_i	Translation along z-axis	Variable	Joint
Link Length	a_i	Translation along x-axis	Constant	Link
Joint type	α_i	Rotation about x-axis	Constant	Link

Robot arm Kinematics Design kinematics analysis of arm robot manipulator starts from forward kinematics. Forward kinematics utilizes mechanical parameters to calculate robot configuration and inverse kinematics to reverse the derivation to acquire the desired configuration.

The kinematics of the manipulator is to establish the relationship between the position and attitude of the manipulator space and the movement of each joint, which provides the method to analysis the control of the manipulator motion. In this paper, the kinematic model is built with 4-DOF manipulator, the forward and inverse kinematic and the working space diagram of the manipulator and trajectory planning are analysis and simulated by using robotanalyzer software.

The kinematics coordinate system of 4-DOF serial manipulator is established by the method of Denavit-Hartenberg [1], as shown in Figure 3.12. $\theta_1, \theta_2, \theta_3, \theta_4$ Is the rotation angle of four joints.

**Figure 3.12:-The kinematic coordinate system of 4-DoF serial manipulator** (Dewi, October, 2019)

Joint 1 linked with base, so we take joint 1 and base as a whole to simplify computing, take the coordinate system of this joint as the base coordinate of manipulator. All joints are revolute joints and the axes of joint 2, 3 and 4 are parallel, the end effector of manipulator is joint 5. According to the structure and the kinematic coordinate system of the manipulator, we get the parameters of each joint and link.

Table 3.8 Denavit Hertzberg parameters (Bao Guangbing, 2017)

No	θ_i	d_i	a_{i-1}	α_{i-1}
1	θ_1	d_1	0	α_1
2	θ_2	0	a_1	0
3	θ_3	0	a_2	0
4	θ_4	0	a_3	α_2

The shortest distance between Z axes of adjacent joints is a_i , d_i is the shortest distance between x-axes of adjacent joints. The angle between the z_{i-1} axis when projection Z_i axis onto the plane of (z_{i-1}, y_{i-1}) is α_i , and θ_i is the angle between the X_{i-1} axes after projection X_i axis onto the plane of (x_{i-1}, y_{i-1})

In order to define the transformation matrix of the whole system we have to determine the relation between each pair of consecutive joints following defined motions that would make the assigned reference frame overlap. This step includes rotation about the z-axis for an angle θ (that would make the x-axis parallel to each other), then translation along the z-axis for a distance d (that would make x-axes collinear), then translation along x-axis for a distance a (that would bring the origins of the two joints together) and at the end rotation of the x-axis about angle of α to align the two z-axis. Following the given sequence of four movements would make the two frames identical. This is done until the end effector is reached, at which point all of the reference systems would be identical. The values of the four D-H parameters are needed to form the so called A-matrix for each joint, which would later yield the transformation matrix.

3.6.2.1. Forward Kinematics (Bao Guangbing, 2017)

The forward kinematics uses parameters to calculate the robot configuration, and the kinematic inverse reverses this calculation to determine the parameters in achieving the desired configuration. There are two ways to solve inverse kinematics of a robot that is using the inverse kinematic trigonometry method and Denavit Hartenberg (DH) shown in table 3.8. In this study, the mechanical parameters are achieved by deriving DH analysis to get the transformation matrix. The robot parameters from figure 3.12 are sorted in Table 3.8, and the transformation matrix is given by

The forward kinematics of the manipulator is to get the desired position of the end effector of manipulator in the base coordinate system by known the angle of each joint. According to the method of D-H (Bao Guangbing, 2017) and the kinematic coordinate system of the manipulator, the corresponding relationship between the two adjacent links is established.

The relative position and attitude transformation matrix of two adjacent links T_i^i ($i=1, 2, \dots, 5$) can be obtained by this correspondence.

The generic form of forward kinematics of an arm robot manipulator is given by

$${}^{i-1}T_i = \text{Forward kinematics } [P]$$

$${}^{i-1}T_i = \text{Trans}_z(d_i)\text{Rot}_z(\theta_i)\text{Trans}_x(a_{i-1})\text{Rot}_x(\alpha_{i-1}) \text{-----} 1$$

$${}^{i-1}T_i = \begin{bmatrix} \cos\theta_i & -\sin\theta_i & 0 & a_{i-1} \\ \sin\theta_i\cos\alpha_{i-1} & \cos\theta_i\cos\alpha_{i-1} & -\sin\alpha_{i-1} & -\sin\alpha_{i-1}a_{i-1}d_i \\ \sin\theta_i\sin\alpha_{i-1} & \cos\theta_i\sin\alpha_{i-1} & \cos\alpha_{i-1} & \cos\alpha_{i-1}d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$${}^0T_1 = \begin{bmatrix} \cos\theta_1 & -\sin\theta_1 & 0 & 0 \\ \sin\theta_1\cos\alpha_1 & \cos\theta_1\cos\alpha_1 & -\sin\theta_1 & 0 \\ \sin\theta_1\sin\alpha_1 & \cos\theta_1\sin\alpha_1 & \cos\theta_1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad {}^2T_1 = \begin{bmatrix} \cos\theta_2 & -\sin\theta_2 & 0 & 0 \\ \sin\theta_2 & \cos\theta_2 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$${}^2_3T = \begin{bmatrix} \cos\theta_3 & -\sin\theta_3 & 0 & \alpha_2 \\ \sin\theta_3 & \cos\theta_3 & -\sin\theta_1 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad {}^4_3T = \begin{bmatrix} \cos\theta_4 & -\sin\theta_4 & 0 & \alpha_3 \\ \sin\theta_4 & \cos\theta_4 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \text{---2}$$

The transformation matrix of the end effector coordinate system relative to the base coordinate system can be obtained by multiply the coordinate transformation matrix of each adjacent links:

$$T = {}^0_1T {}^1_2T {}^2_3T {}^3_4T {}^4_5T = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} c_1c_{234} & -c_1s_{234} & -s_1 & a_2c_1 + a_3c_1c_2 + a_4c_1c_{23} + a_5c_1c_{234} - d_2s_1 \\ s_1c_{234} & -s_1s_{234} & c_1 & a_2s_1 + a_3s_1c_2 + a_4s_1c_{23} + a_5s_1c_{234} + d_2c_1 \\ -s_{234} & -c_{234} & 0 & d_1 - a_3s_2 - a_4s_{23} - a_5s_{234} \\ 0 & 0 & 0 & 1 \end{bmatrix} \text{-----3}$$

In the formula above, the position of the end effector of the manipulator is described by

$$C_{ijk} = [p_x, p_y, p_z]^T, S_{ij} = \sin(\theta_i + \theta_j), C_{ij} = \cos(\theta_i + \theta_j), S_{ijk} = \sin(\theta_i + \theta_j + \theta_k) \\ C_{ijk} = \cos(\theta_i + \theta_j + \theta_k), \quad (i, j, k = 1, 2, 3, 4)$$

After completing the forward kinematics the invers kinematics is proceed to get the motion parameters of each manipulator joint by known structural parameters and the position and attitude of the end effector

3.6.2.2. Invers Kinematics

Inverse kinematics is the mathematical calculation for finding the parameters in forward kinematics, and by knowing the best value for each parameter in Table 1, the desired position and orientation of the robot is achieved. The derivation of inverse kinematics is a challenging mathematical task, especially when the angles are more than 2. In this study, the inverse kinematics is only to find 1 to 3. (Tresna Dewi et.al, October, 2019)

The kinematics inverse plays an important role in the kinematics of robot, which is the precondition of kinematics analysis, motion space, offline programming and trajectory planning.

While the inverse kinematics of an arm robot manipulator is given by

$$[P] = \text{Forwad kinematics } {}^0_3T \text{-----4}$$

Where [P] is the desired position in x, y, and z-axis. i_3T is the kinematics solution of the robot. Inverse kinematics results are the angle of robot's motion links by modeling robot parameters based on the target position, the length of the link, the angle between links and those parameters becomes the input to get the transformation matrices. Those matrices are the forward kinematics required to get inverse kinematics.

Solving for inverse kinematics

1) Solving θ_1

Obtained by formula (3).

$$\frac{n_y}{n_x} = \tan \theta_i, \tan \theta_1 = A \tan 2(n_y, n_x)$$

$$\theta_1 = \text{atan2}(p_x^2 + p_y^2 - (a_2 \cos \theta_2 + a_1)^2, a_2 \cos \theta_2 + a_1) \text{-----} 5$$

2) Solving for Solving θ_3

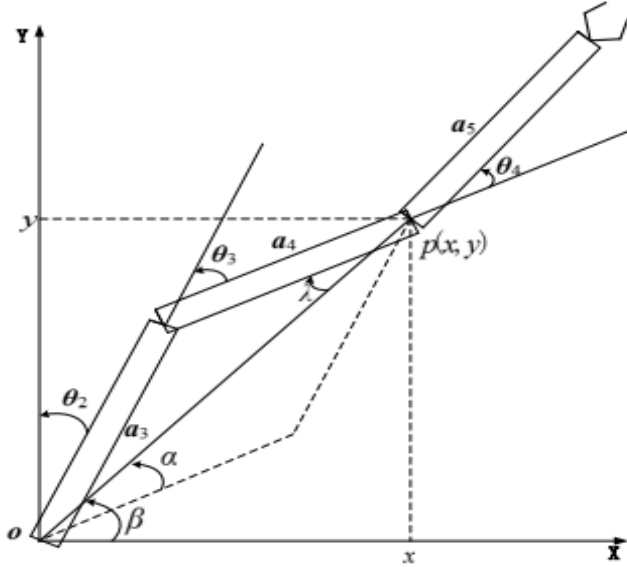


Figure 3.13 Partial joints of manipulator (Bao Guangbing, 2017)

As shown in figure 3.13, this is the structure of the joints of 4-DOF manipulator except the waist joint, in the triangle consist of a_3 , a_4 and p_o , based on cosine theorem. θ_3 Is obtained by formula (4), 5) .

$$x^2 + y^2 = a_3^2 + a_4^2 - 2a_3a_4 \cos(180 - \theta_3) \text{-----} 6$$

$$\cos \theta_3 = \frac{x^2 + y^2 - a_3^2 - a_4^2}{2a_3a_4} \text{-----} 7$$

$$\theta_3 = \pm a \tan 2(p_x^2 + p_y^2 - (a_2 \cos \theta_{12} + a_1)^2, a_2 \cos \theta_{12} + a_1) \text{-----} 8$$

(3) Solving θ_2

In order to obtain θ_2 , we first calculate the angle α and β , figure 3.13 is shown.

$$\tan \beta = \frac{y}{x}, \beta = \text{atan2}(x, y) \text{-----} 9$$

$$\cos \alpha = \frac{x^2 + y^2 + a_3^2 - a_4^2}{2a_3\sqrt{x^2 + y^2}} \text{-----} 10$$

Obtained by formula (9)(10) $\theta_2 = \beta \pm \alpha$ ($\theta_3 < 0$ is $\theta_3 > 0$ is -

(4) Solving 4

Obtained by formula (3) .

$$\theta_2 + \theta_3 + \theta_4 = \text{Atan2}(n_z, o_z) \text{-----} 11$$

$$\theta_4 = \text{Atan2}(\text{Atan2}(n_z, o_z) - \theta_2 - \theta_3) \text{-----} 12$$

Then the angle of inverse kinematic of the four joints of manipulator is obtained by the method above. Algebraic method can easily solve one or a few joints angle. It eliminates the complexity of matrix calculation.

The manipulator consists of four rotating and bending joints has clearly structure and few freedom. Combined with the method of geometric method with algebraic method can be easier get the relationship between angles according to the characteristics of these two methods, it can simplifies tedious mathematic operation in the process of inverse kinematics and quickly get the angle of each joints.

3.6.2.3. Demonstrated kinematic model

In order to verify the kinematic model of the robotic arm, we have created a simulator that visualizes its exact configuration, as shown in figure 3.14. By specifying the desired orientation and position of the point where we want the arm to be placed in the three dimensional space, the program can calculate the needed angles, which are afterwards being sent to a virtual serial port, following a specific, previously defined, communication protocol. The simulator opens another serial port which is bridged to the aforementioned, and according to the data being received, moves the robotic arm, making it visible if the desired location has indeed been reached. (Bao Guangbing, 2017). In this simulation only few point which enable us to see the overall configuration are model using forward kinematics. The simulation are done using robotanalyzer software

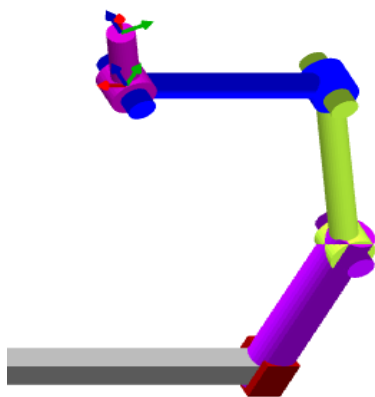


Figure 3.14 created robotic arm for simulation

3.6.2.4. Step in robot arm kinematics simulation

1. Open robotanalyzer software, to create robot arm and set the parameters

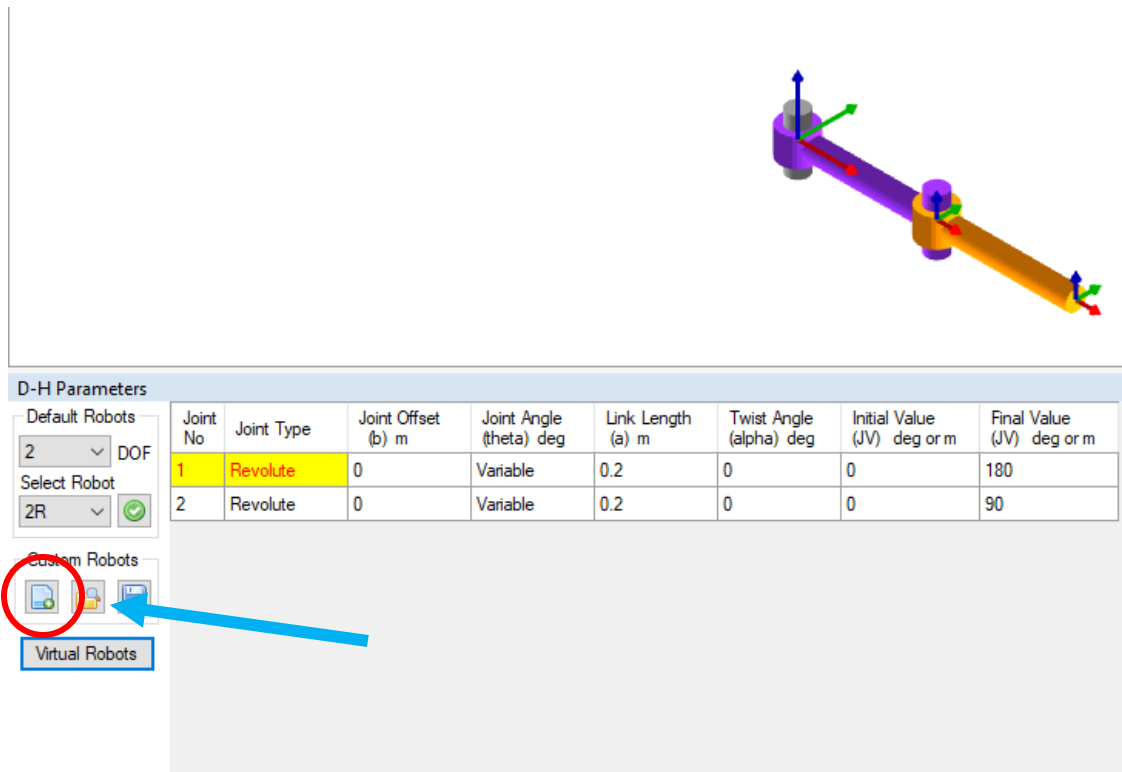


Figure 3.15. Creating blank robotanalyzer

- Set The DH parameters on the dial box appeared and then click on create robot i.e. parameters may be changed after model created for better visualization

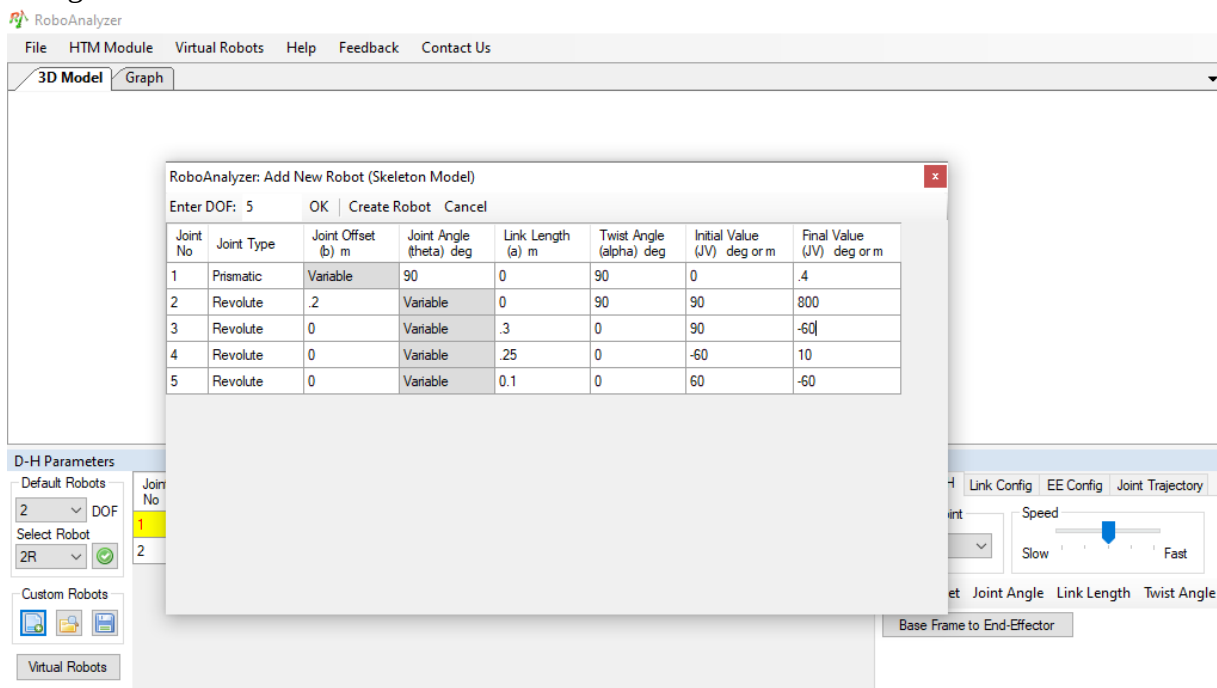
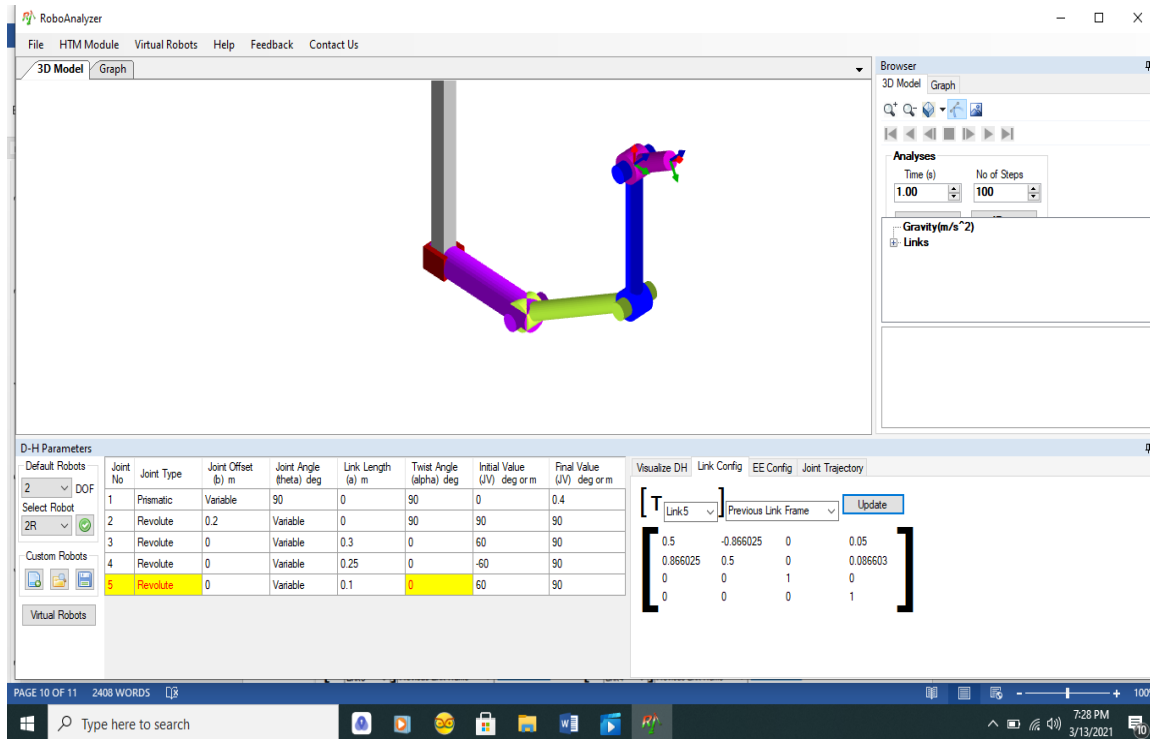


Figure 3.16. Creating the robot arm



D-H Parameters

Default Robots: 2 DOF
Select Robot: 2R
Custom Robots: [Icons]
Virtual Robots: [Button]

Joint No	Joint Type	Joint Offset (b) m	Joint Angle (theta) deg	Link Length (a) m	Twist Angle (alpha) deg	Initial Value (JV) deg or m	Final Value (JV) deg or m
1	Prismatic	Variable	90	0	90	0	0.4
2	Revolute	0.2	Variable	0	90	90	8000
3	Revolute	0	Variable	0.3	0	60	-30
4	Revolute	0	Variable	0.25	0	-60	-30
5	Revolute	0	Variable	0.1	0	60	-30

Figure 3.16 Setting parameters as required

In this parameter twist angle is the angle between two adjacent joint, initial value is the angle θ which initially located in local work space where final value is the final destination of that specific arm joint angle θ . This two value becomes degree where revolute joint and m in case of prismatic movement or straight movement

3. Generate transformation matrix of between joints

Visualize DH | Link Config | EE Config | Joint Trajectory

Visualize DH | Link Config | EE Config | Joint Trajectory

Link1 Base Frame Update

$$\begin{bmatrix} T_{Link1} \\ 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Link2 Previous Link Frame Update

$$\begin{bmatrix} T_{Link2} \\ 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0.2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

5. Generating graph of the overall joint movement are shown below

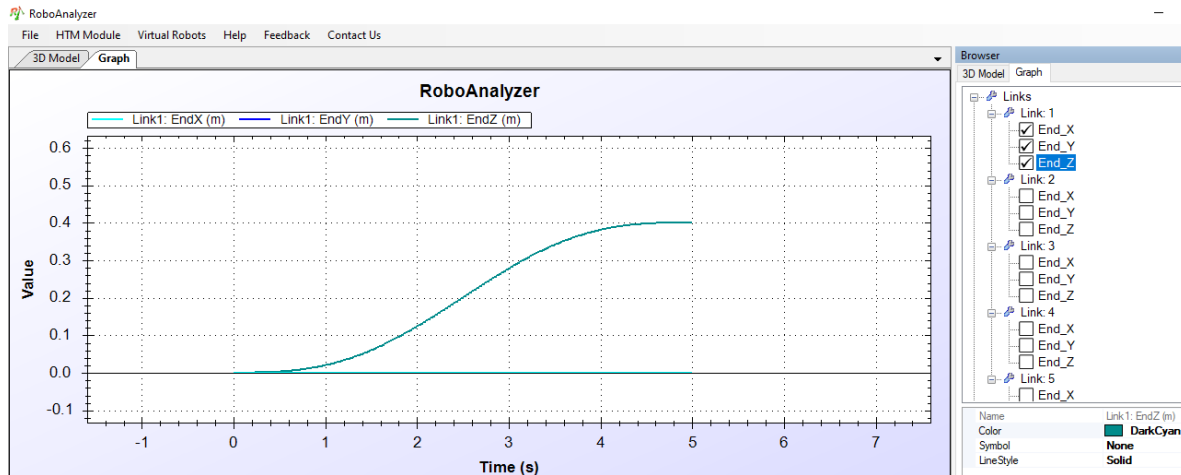


Figure 3.19. Generated graph Link 1,

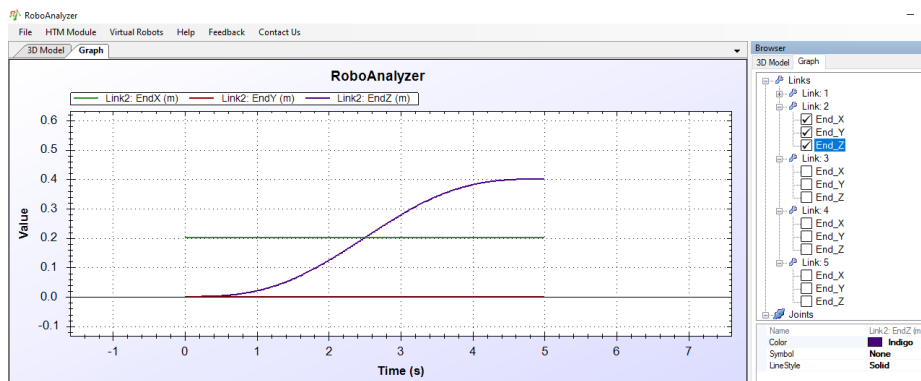


Figure 3.20. Generated graph Link 2,

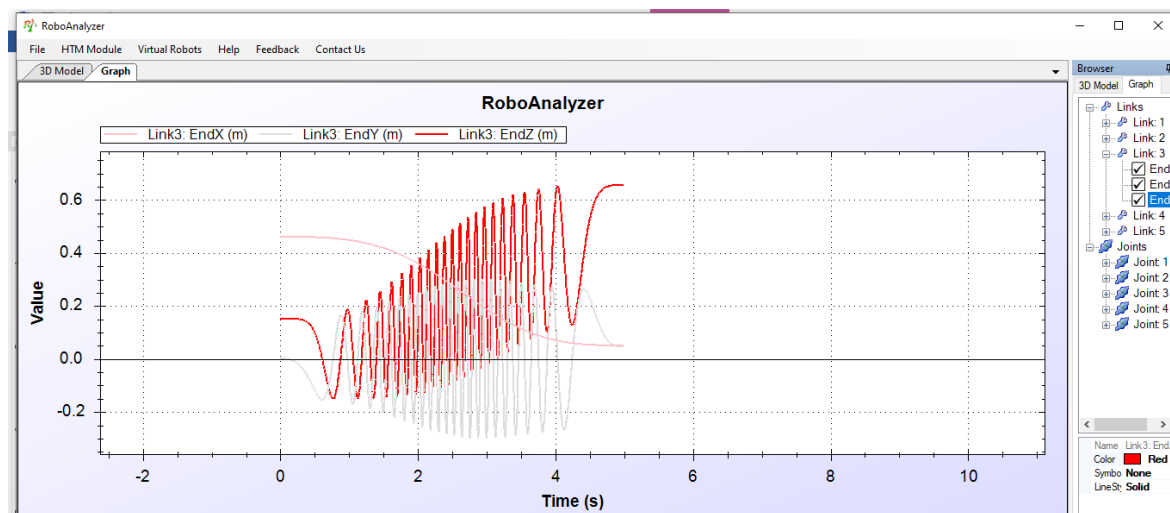


Figure 3.21. Generated graph Link 3,

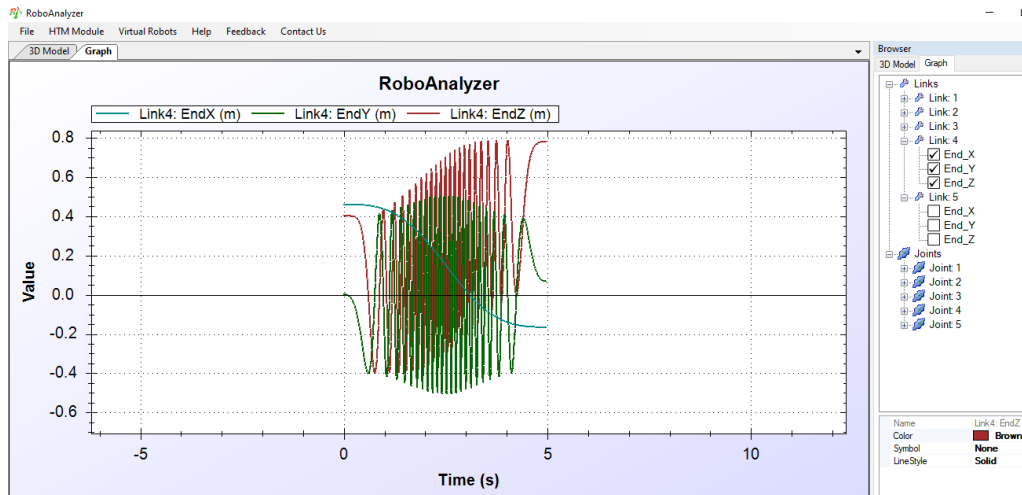


Figure 3.22. Generated graph Link 4,

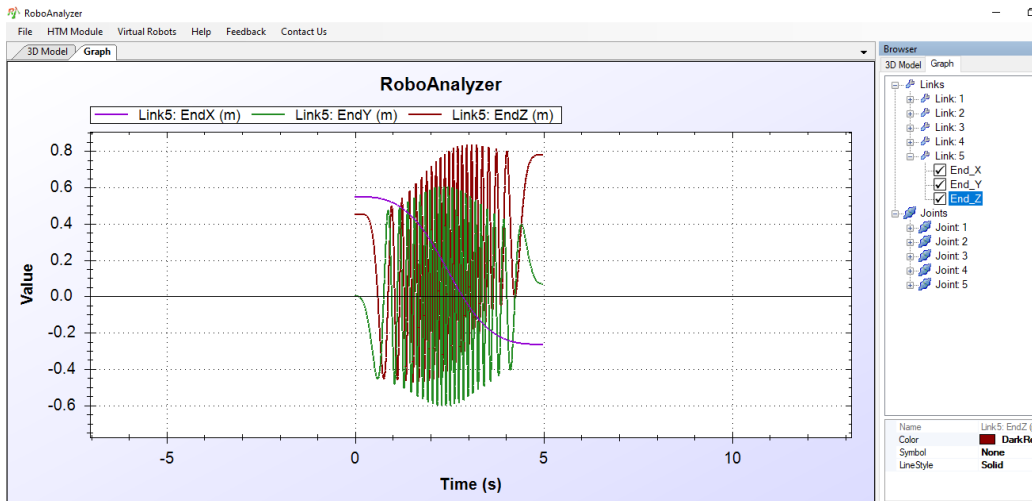


Figure 3.23. Generated graph Link 5,

6. Joints movement graph generated

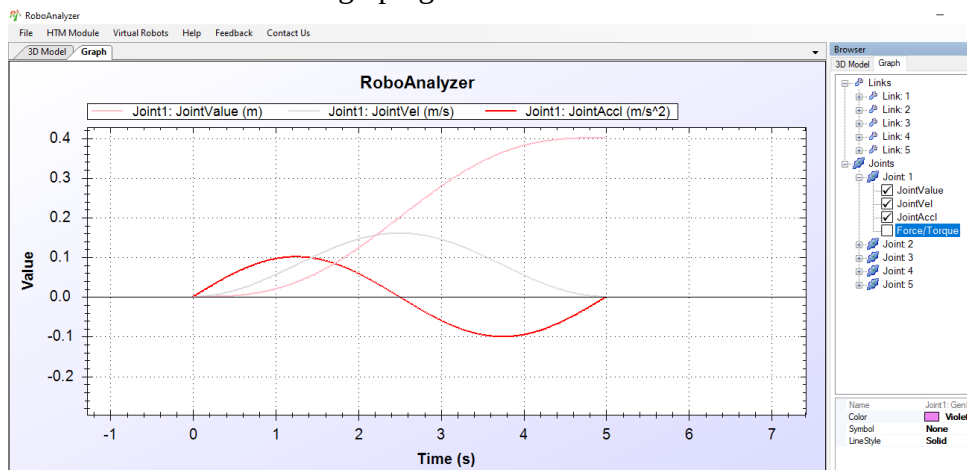


Figure 3.24. Generated graph joints 1,

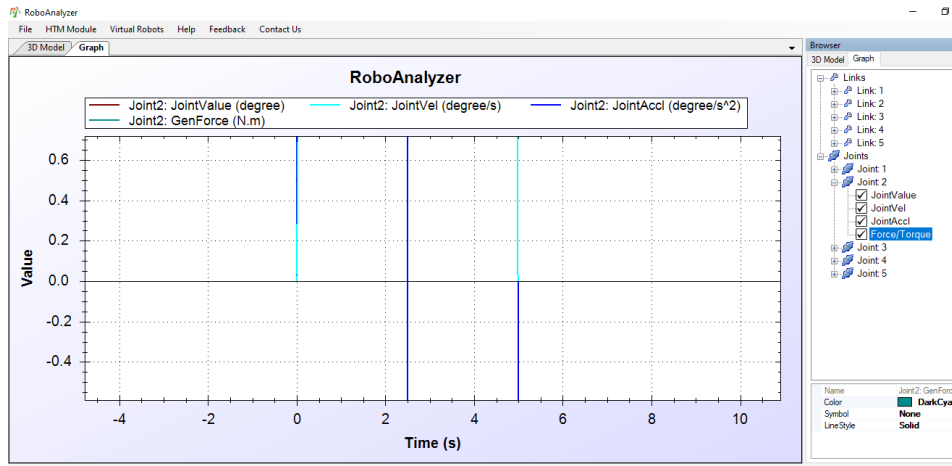


Figure 3.25. Generated graph joints 2,

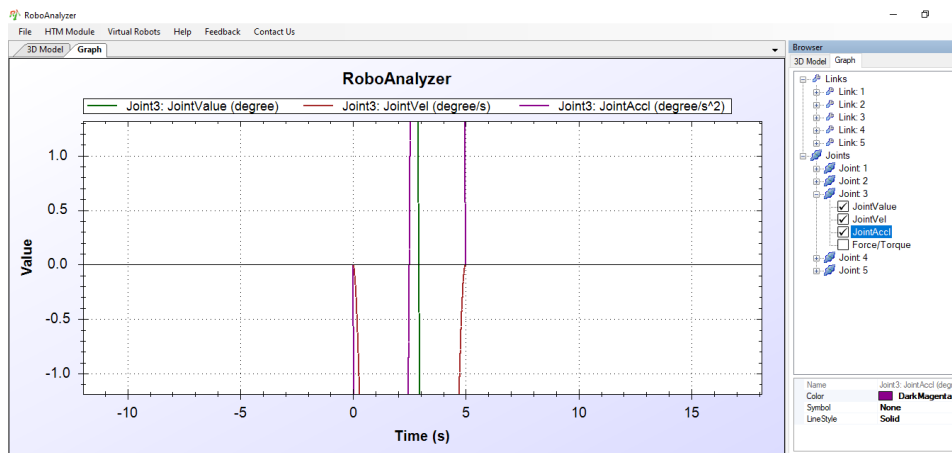


Figure 3.26. Generated graph joints 3,

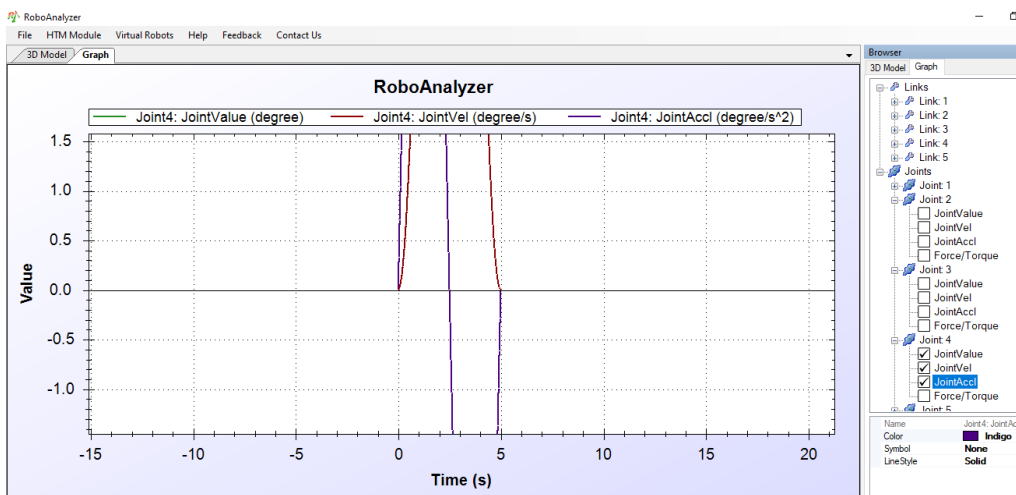


Figure 3.27. Generated graph joints 4,

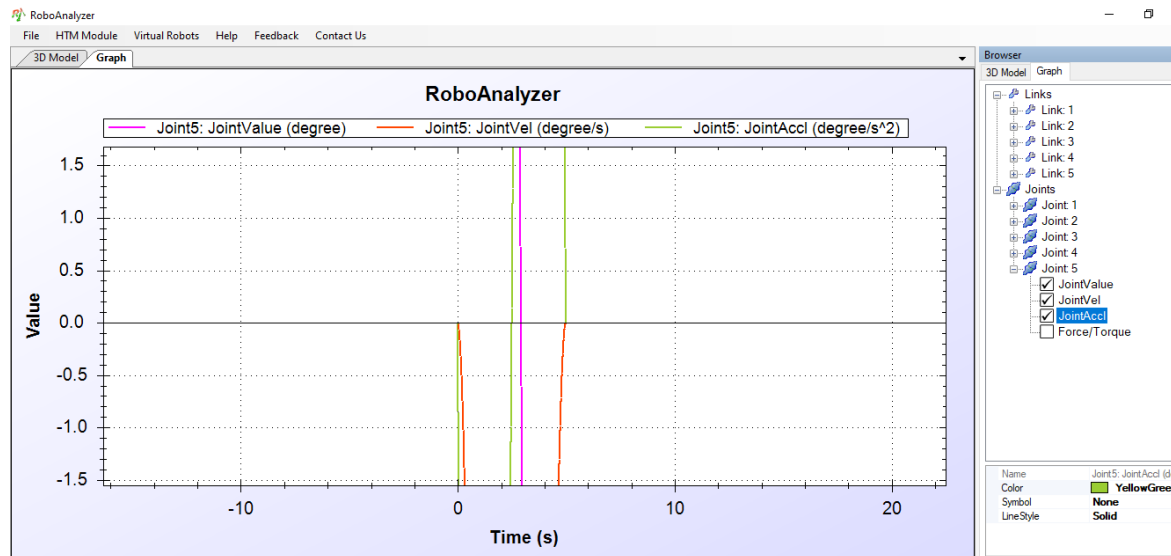


Figure 3.28. Generated graph joints 5,

7. Summary of simulation

This kinematics simulation is performed on the basis of the specific point which can be basic for the overall visualization of end effector.

Denavit-Hartenberg model usage of the D-H representation is recommended in cases of robotic arm configurations where more than one joint of the robot are intersecting at a common point. Since this configuration is not the case, the main drawback of the D-H representation, becomes evident. The system of equations can be really difficult for solving, which was the case when solving the above specified system, and furthermore, in some cases it could be even impossible. It was solved using a replacement method since it consists of non-linear simultaneous equations. As known, this method does not always guarantee results. On the other hand, there is no standardized way of solving it, except if using numerical approximations, which procedure is not applicable where the precision is key element. This is also worth considering, taking into account that if a new joint is added to this robot arm configuration, the whole kinematic model should be recalculated. This is very likely to happen, as for example if we want to add another revolute joint at the end effector. (Dewi, October, 2019)

Another notable disadvantage of the D-H representation is the existence of singularities. Dealing up with them adds to the total amount of time required to compute the values for the angles. Furthermore, since many times while solving the system some of the equations need to be squared, each of the yielded results should later be validated. Therefore, the total time needed to calculate the angles might be a problem. This problem becomes more evident if the robotic arm is being used in applications where, for example, it needs to follow a specific shape of line. In such cases the computations should be done quickly in order the yielded values to be sent sequentially as a set of points. (Dewi, October, 2019)

3.7. Arm control options

3.7.1.Option-1: Potentiometer

A simple method for the movement of a Robotic Arm was monitored and controlled by using a potentiometer. This system is built to control every joint movement manually. The potentiometer is attached to the motors of waist, shoulder, elbow, robot base rotating and gripper rotation using Arduino

microcontroller. As the potentiometer resistance changes the motor with respective joint motor rotate with the arm attached with it.

3.7.2. Option-2: Computer program

Arduino program from personal computer is used to program. Program from computer sent to the different robot arm servo motor to move the tools to the required position which is fixed on the end effector (gripper) of the robot arm.

3.7.3. Option-3; Bluetooth device

A Bluetooth synchronization device is applied on the Arduino control circuit board and from by any Bluetooth supported hand device controlled remotely to get in to the intended position.

3.8. Static Torque Calculation

The following calculation was carried out in order to ensure that the torque of the elbow and shoulder motors enough to rotate the joints with a maximum payload of 1.5kg. The maximum required torque corresponding to the worst-case scenario with the arm fully stretched out is shown in Fig. 3.7.

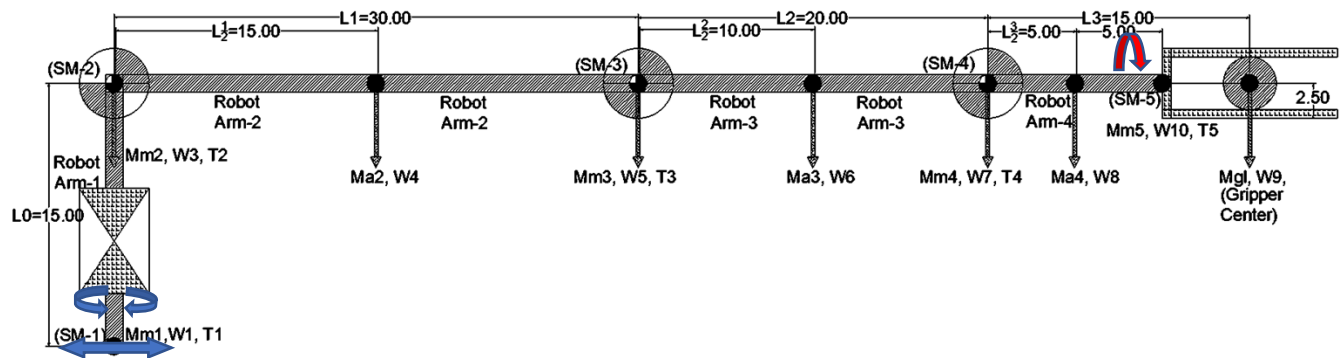


Fig 3.29 Load free body diagram of robot arm

3.8.1. Torque exists at each joint

Before starting the calculation of torque at each joint let summarize the standards and other main data from concept design work

Msm_i – mass of corresponding servo motor at the analogous joint

Ma_i – mass of corresponding mechanical arm

W_i - Weight at corresponding points

L_i – Length of corresponding mechanical arm

w- Width of arm

t- Thickness of arm

g- Gravitational acceleration = 9.8m/s^2

Material type = Aluminum

ρ – Density = 2.70g/cm^3

Other given

Table 3.9 Primary design data of robotic arm

S. No	Description	Symbol	Unit	Quantity	S. No	Description	Symbol	Unit	Quantity
1.	Arm length 1, width and thickness	$L_0 \times w \times t$	cm	$15 \times 5 \times 0.3$	1.	Mass of motor 1	M_{m1}	kg	0.68
2.	Arm length 2, width and thickness	$L_1 \times w \times t$	cm	$30 \times 5 \times 0.3$	2.	Mass of motor 2	M_{m2}	kg	0.68
3.	Arm length 3, width and thickness	$L_2 \times w \times t$	cm	$20 \times 5 \times 0.3$	3.	Mass of motor 3	M_{m3}	kg	0.68
4.	Arm length 4, width and thickness	$L_3 \times w \times t$	cm	$15 \times 5 \times 0.3$	4.	Mass of gripper and live load	M_{gl}	kg	1.55
5.	Mass of arm 1	M_1	kg	0.21	NB: - ❖ Mass of servo motors are taken from standard supplier data ❖ Mass of mechanical arm is found from calculation below				
6.	Mass of arm 2	M_2	kg	0.42					
7.	Mass of arm 3	M_3	kg	0.27					
8.	Mass of arm 4	M_4	kg	0.21					

$$W_0 = M_1 \times g = 0.21 \text{ kg} \times 9.8 \text{ m/s}^2 = 2.058 \text{ N}$$

$$W_1 = M_{m1} \times g = 0.68 \text{ kg} \times 9.8 \text{ m/s}^2 = 6.664 \text{ N}$$

$$W_2 = M_{a1} \times g = 0.21 \text{ kg} \times 9.8 \text{ m/s}^2 = 2.058 \text{ N}$$

$$W_3 = M_{m2} \times g = 0.68 \text{ kg} \times 9.8 \text{ m/s}^2 = 6.664 \text{ N}$$

$$W_4 = M_{a2} \times g = 0.41 \text{ kg} \times 9.8 \text{ m/s}^2 = 4.018 \text{ N}$$

$$W_5 = M_{m3} \times g = 0.68 \text{ kg} \times 9.8 \text{ m/s}^2 = 6.664 \text{ N}$$

$$W_6 = M_{a3} \times g = 0.27 \text{ kg} \times 9.8 \text{ m/s}^2 = 2.646 \text{ N}$$

$$W_7 = M_{m4} \times g = 0.68 \text{ kg} \times 9.8 \text{ m/s}^2 = 6.664 \text{ N}$$

$$W_8 = M_{a4} \times g = 0.21 \text{ kg} \times 9.8 \text{ m/s}^2 = 2.058 \text{ N}$$

$$W_9 = M_{gl} \times g = 1.55 \text{ kg} \times 9.8 \text{ m/s}^2 = 15.98 \text{ N}$$

$$W_{10} = M_{gl} \times g = 1.55 \text{ kg} \times 9.8 \text{ m/s}^2 = 15.98 \text{ N}$$

The arm mass is calculated as follow

$$\rho = \frac{m}{V} \quad \text{Where, } m \text{ is corresponding arm mass and } V \text{ is volume of the arm}$$

$$V_i = L_i \times w \times t$$

$$V_1 = 15 \times 5 \times 0.5 \text{ cm}^3 = 37.5 \text{ cm}^3$$

$$V_2 = 30 \times 5 \times 0.5 \text{ cm}^3 = 75 \text{ cm}^3$$

$$V_3 = 20 \times 5 \times 0.5 \text{ cm}^3 = 50 \text{ cm}^3$$

$$V_4 = 15 \times 5 \times 0.5 \text{cm}^3 = 37.5 \text{cm}^3$$

$$\text{Hence, } M_i = V_i \times \rho$$

$$M_{a1} = 37.5 \text{cm}^3 \times 2.70 \text{g/cm}^3 = 102.25 \text{g}$$

$$M_{a2} = 75 \text{cm}^3 \times 2.70 \text{g/cm}^3 = 202.5 \text{g}$$

$$M_{a3} = 50 \text{cm}^3 \times 2.70 \text{g/cm}^3 = 135 \text{g}$$

$$M_{a4} = 37.5 \text{cm}^3 \times 2.70 \text{g/cm}^3 = 102.25 \text{g}$$

Since, we have two parallel frame in one arm the total weight becomes 2 times the above values. i.e.

$$M_{a1} = 102.25 \text{g} \times 2 = 204.5 \text{g}$$

$$M_{a2} = 75 \text{cm}^3 \times 2.70 \text{g/cm}^3 \times 2 = 405 \text{g}$$

$$M_{a3} = 50 \text{cm}^3 \times 2.70 \text{g/cm}^3 \times 2 = 270 \text{g}$$

$$M_{a4} = 37.5 \text{cm}^3 \times 2.70 \text{g/cm}^3 \times 2 = 204.5 \text{g}$$

$$T_4 = W_9 \times L_4 + \frac{L_4}{2} \times W_7$$

$$T_4 = 15.98 \text{N} \times 15 \text{cm} + \frac{10 \text{cm}}{2} \times 2.058 \text{N}$$

$$T_4 = 249.99 \text{N.cm}$$

$$T_3 = W_9 \times (L_4 + L_3) + \left(L_3 + \frac{L_4}{2}\right) \times W_8 + L_3 \times W_7 + \frac{L_3}{2} \times W_6$$

$$T_3 = 15.98 \text{N} \times (15 \text{cm} + 20 \text{cm}) + \left(20 + \frac{10}{2}\right) \text{cm} \times 2.058 \text{N} + 6.664 \text{N} \times \frac{20}{2} \text{cm} + \frac{20}{2} \times 2.646 \text{N}$$

$$T_3 = 703.85 \text{N.cm}$$

$$T_2 = W_9 \times (L_4 + L_3 + L_2) + W_8 \times \left(L_3 + \frac{L_4}{2} + L_2\right) + W_7 \times (L_2 + L_3) + W_6 \times \left(\frac{L_3}{2} + L_2\right) + L_2 \times W_5 + W_4 \times \frac{L_2}{2}$$

Since there is no horizontal distance between torque at joint 0 and joint 1 their torque become the same i.e.

$$T_2 = T_1$$

$$T_2 = T_1 = 15.98 \text{N} \times (30 + 20 + 15) \text{cm} + 2.058 \text{N} \times \left(20 + \frac{10}{2} + 30\right) \text{cm} + 6.664 \text{N} \times$$

$$(20 + 30) \text{cm} + 2.646 \text{N} \times \left(\frac{20}{2} + 20\right) + 20 \text{cm} \times 6.664 \text{N} + 4.018 \text{N} \times \frac{30}{2} \text{cm}$$

$$T_2 = T_1 = 1758.02 \text{Ncm}$$

$$T_5 = W_{10} \times 2.5 \text{cm}$$

$$T_5 = 15.98 \text{N} \times 2.5 \text{cm}$$

$$T_5 = 39.95 \text{Ncm}$$

As a summary

$$T_1 = 1758.02\text{Ncm} \quad T_2 = 1758.02\text{Ncm} \quad T_3 = 703.85\text{Ncm} \quad T_4 = 249.99\text{Ncm} \quad T_5 = 39.95\text{Ncm}$$

Table 3.10 Torque in arm joints

Force between	In Ncm	In kgcm
Arm-1 and base	891.80	90.94
Arm-1 and Arm-2	1758.02	179.27
Arm-2 and Arm-3	703.85	71.77
Arm-3 and gripper	249.99	25.49
Gripper and torch	39.95	4.07

NB: - The value in Kgcm is approximated

3.8.2. Result and Interpretation

From the moment's equilibrium equations, the results showed that a minimum of 0.40Nm for the gripper, 2.50Nm for the wrist, 7.04Nm for elbow and 17.58Nm for shoulder are required. For the purpose of the project suitability and its cost the optimal motor capacity selected and purchased from the markets are two types, i.e. 100kgcm arm, 15kgcm for gripper and a geared DC motor with 46kgcm. From final result it can be concluded that continuing with the same design will fail due to the capacity of motor in hand. Therefore, reducing arm-4 and developing robotic arm with five degree is recommended as a solution. Here by the data converted below. Since all the calculation procedure are the same and only the values of L_3 become 0. Since there is a program developed on excel the result is collected from it.

Table 3.11 Torque in arm joints after redesign

Force between	In Ncm	In kgcm
Arm-1 and base	768.2	78.33
Arm-1 and Arm-2	1440.85	146.92
Arm-2 and Arm-3	516.66	52.68
Arm-3 and gripper	73.5	7.49
Gripper and torch	36.75	3.75

NB: - The value in kg.cm is approximated

3.8.3. Decisions

Before decision the other points to be taken in to consideration is the motor efficiency which is standard 82% is taken here. Accordingly, the motor we have in hand which are designed capacity are 100kgcm and 15kgcm become a working efficiency of 82kgcm and 12.3kgcm respectively. The followings are the decision made on robot arm product design

1. For gripping and gripper rotation 15kgcm is acceptable and will be used on respective joints
2. From the design arm-3 can be lifted by 100kgcm servo available
3. For arm-2 the capacity of single servo motor we have will not able to lift it. Therefore, a simultaneously operated two 100kgcm will be used which a total of 164kgcm which is greater than 146.92kgcm
4. For motor rotates the whole arm 360° can be used by 100kgcm servo available on hand

3.9. Drive wheel motor torque calculations

When selecting drive wheel motors for mobile robots, a number of factors must be taken into account to determine the maximum torque required. The following example presents one method of computing this torque.

Calculate total weight of robots

Table 3.12 primary data for driver motor (wheel load)

S. No	Description	Mass (kg)	Remarks
1	Pay load and gripper	1.55	
2	Total servo & motors	4.676	
3	Total arm	1.1	
4	Electrical equipment	0.8	
5	Pins and other accessories	0.56	
6	Wheel and axle	0.31	
7	Contingency (15%)	1.35	
Total		10.35 kg	

3.9.1. Robot wheel drive motor design criteria

- Gross robot weight (G_{RW}): 101.43N
- Weight on each drive wheel (W_w): 60N
- Radius of wheel (R_w): 30mm
- Desired top speed (V_{max}): 10 mm/sec
- Desired acceleration time (t_a): 1 sec
- Maximum incline angle (α): 2 degree
- Worst working surface: Steel (good)

To choose motors capable of producing enough torque to propel the example robot, it is necessary to determine the total tractive effort (TTE) requirement for the robot:

$$TTE = RR + GR + F_a$$

Where:

TTE = Total tractive effort

RR = Force necessary to overcome rolling resistance

GR = Force required to climb a grade

F_a = force required to accelerate to final velocity

The components of this equation will be determined in the following steps.

Step One: Determine Rolling Resistance

Rolling Resistance (RR) is the force necessary to propel a robot over a particular surface. The worst possible surface type to be encountered by the robot should be factored into the equation.

$$RR = W_{GR} \times C_{sf}$$

Where:

RR = Rolling resistance force

WGR = Gross robot weight

Csf = Surface rolling friction coefficient. (Value from standard table below)

$$RR = 101.43N \times 0.002$$

$$RR = 0.203N \text{ ----- } 1$$

Table 3.13 Surface rolling friction coefficient standard table

Rolling resistance coefficient		
c	C ₁ (mm)	
0.001-0.002	0.5	Rail road steel wheel on steel wheel
0.001		Bicycle tire on wooden track
0.002-0.005		Low resistance tubeless tire
0.002		Bicycle tire on concrete
0.004		Bicycle tire on asphalt road
0.005		Dirty tram rails
0.006-0.01		Truck tire on asphalt
0.008		Bicycle tire on roughed paved road
0.01-0.015		Ordinary car tire on concrete new asphalt, cobbles new
0.02		Car tire on tar or asphalt
0.02		Car tire on gravel, rolled new
0.03		Car tire on cobbles large wom
0.04-0.08		Car tire on solid sand, gravel loos wom, soil medium hard
0.2-0.4		Car tire on loose sand

Step Two: Determine Grade Resistance

Grade Resistance (GR) is the amount of force necessary to move a robot up a slope or grade. This calculation must be made using the maximum angle or grade the robot expected to climb in normal operation. To convert incline angle, α , to grade resistance:

$$GR = W_{GR} \sin \alpha$$

Where:

GR = Grade resistance; WGR = Gross robot weight

α = maximum incline angle [degrees]

The robot arm only operates in flat surface but for safety the angle will be considered 5 degree

hence,

$$GR = 101.43N \times \sin 5^\circ$$

$$GR = 8.84N \text{ ----- } 2$$

Step Three: Determine Acceleration Force

Acceleration Force (F_a) is the force necessary to accelerate from a stop to maximum speed in a desired time.

$$F_a = \frac{W_{GR} \times V_{max}}{9.82 \frac{m}{s^2} \times t_a}$$

Here:

F_a = Acceleration force

W_{GR} = Gross robot weight

V_{max} = Maximum speed

t_a = Time required to achieve maximum speed [s]

$$F_a = \frac{101.43N \times 0.01 \frac{m}{s}}{9.8 \frac{m}{s^2} \times 2s}$$

$$GR = 0.0518N \text{ -----} 3$$

Step Four: Determine Total Tractive Effort

The Total Tractive Effort (TTE) is the sum of the forces calculated in steps 1, 2, and 3. (On higher speed robot friction in drive components may warrant the addition of 10%-15% to the total tractive effort to ensure acceptable robot performance.)

$$TTE = RR + GR + F_a$$

$$TTE = 0.203N + 8.84N + 0.0518N$$

$$TTE = 9.095N \text{ -----} 4$$

Step Five: Determine Wheel Motor Torque

To verify the robot will perform as designed in regards to tractive effort and acceleration, it is necessary to calculate the required wheel torque (T_w) based on the tractive effort.

$$T_w = TTE \times R_w \times RF$$

Where:

T_w = Wheel torque

TTE = Total tractive effort

R_w = Radius of the wheel

RF = Resistance factor

The resistance factor accounts for the frictional losses between the caster wheels and their axles and the drag on the motor bearings. Typical values range between 1.1 and 1.15 (or 10 to 15%).

$$T_w = 9.095N \times 0.03m \times 1.15$$

$$T_w = 0.30832 \text{ kNm} = 308.32 \text{ Ncm} \text{ -----} 5$$

The total motor torque required will be 308.32Ncm

Step Six: Reality Check

The final step is to verify the robot can transmit the required torque from the drive wheel(s) to the ground. The maximum tractive torque (MTT) a wheel can transmit is equal to the normal load times the friction coefficient between the wheel and the ground times the radius of the drive wheel.

$$MTT = W_w \times \mu_s \times R_w$$

Where:

W_w = weight (normal load) on drive wheel

μ_s = static friction coefficient between the wheel and the rail (~0.75 for dry steel on dry steel)

R_w = radius of drive wheel

$$MTT = 60N \times 0.75 \times 0.03m$$

$$MTT = 1.35Nm = 135.00Ncm$$

3.9.2. Interpreting Results

TTE is a net force applied horizontally by the drive wheels to the ground. If there is two drive wheels, the force applied in each wheel (in straight movement) is half of the calculated TTE. The wheel torque calculated in step five on appendix II is the overall wheel torque. This amount does not change with the number of drive wheels. The total drive motor torques have to be greater than or equal to the calculated wheel torque. The largest tractive torque represents the optimum amount of torque that can be applied before slipping occurs for each drive wheel. *The total wheel torque calculated in step five must be less than the sum of the maximum tractive torques for all drive wheels or slipping will occur.*

3.10. FEM analysis of Mechanical arm

The FEM analysis is done with CATIA V5 generative structure the overall step followed, the engineering data used and the result from the model are described below.

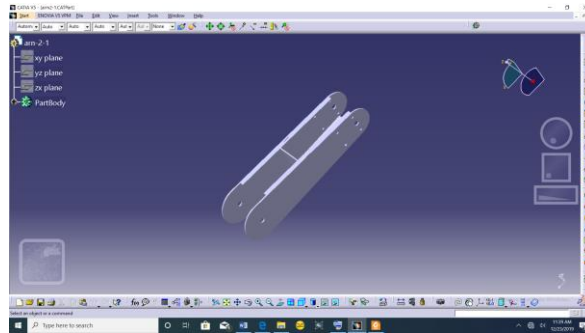
3.10.1. Procedure in Catia Version 5 Generative Structural Analysis

In analyzing the FEM model of the arm it will be easier to calculate with arm applied the highest torque. From all the arm robotic arm 2 is the one with higher torque which is 1758.0Ncm FEM Model are done using a CATIA general structural analysis which helps to acquire various structural behavior of the part in 3D model before proceeding to the manufacturing operation. The Generative structural analysis workbenches utilize the numerical approximation methods of FEM. This method works by approximating the model by breaking it more simplified and smaller pieces. These broken-down pieces are referred to as elements. The point at which elements are connected is called nodes. The following illustration will provide greater clarity on the overall steps and product behavior.

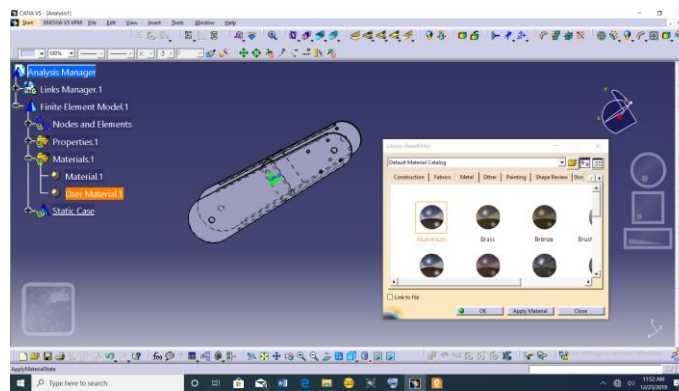
Input data are

Steps in FEM analysis

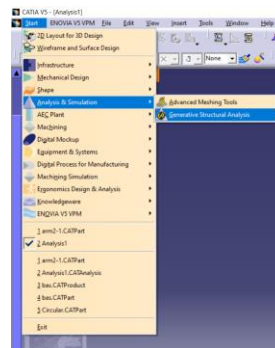
1. Draw a 3D model of robot arm-2 and open



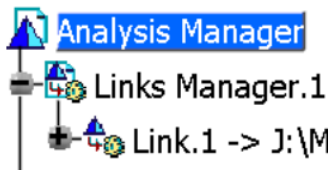
2. Select a material for arm  a material library below appears and select material type aluminum



3. **Switch to the Generative Structural Analysis workbench.** It is located in the *Start* menu under *Analysis and Simulation*. This will create an analysis of the part. The CAT Analysis will be linked back to the original part as shown below.

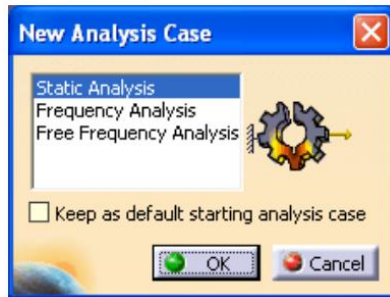


4. **Select the Static Analysis case and select OK.** This creates a *Static Case* analysis document. You will see the *Static Case* branch in the specification tree below appears. Select static analysis from new case analysis window.

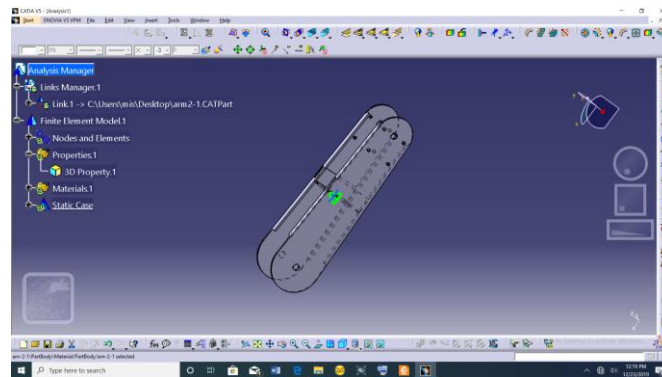


Link.1 -> J:\Manuals\CATIA V5 Stress Analysis\R19\Models\Basic.CATPart

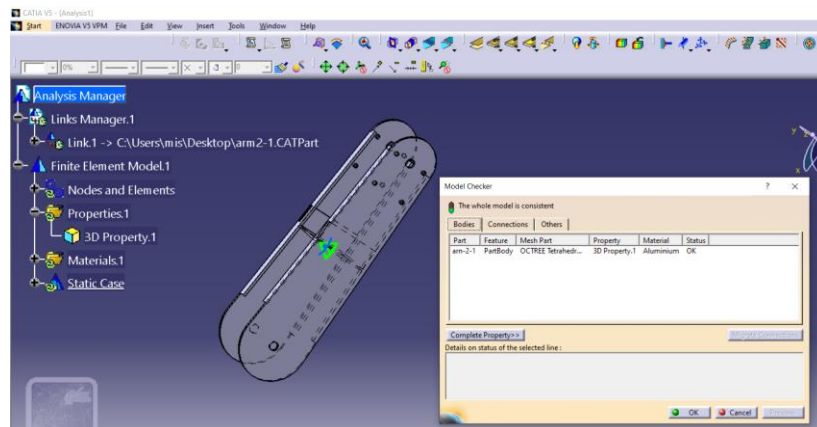
The *New Analysis Case* window appears. You have to define what type of analysis you would like to do.



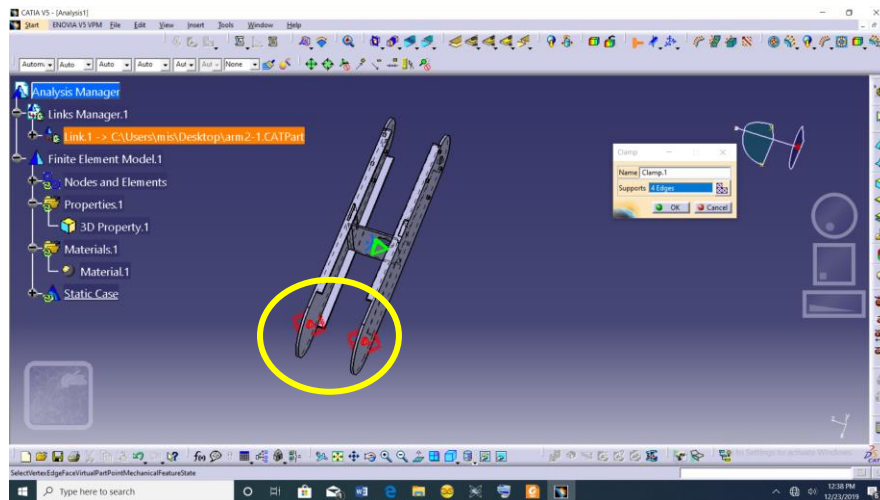
Select the *Static Analysis* case and select **OK**. This creates a *Static Case* analysis document. You will see the *Static Case* branch in the specification tree. You actually have a new document up at this point. The mesh and model properties are represented by the following symbols in the 3D environment



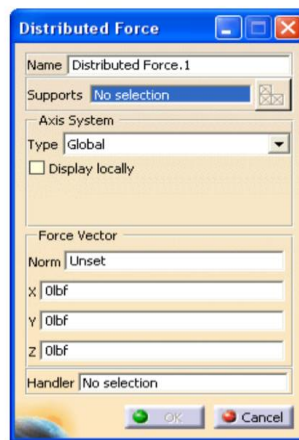
5. Select the **Model Checker** icon.  The *Model Checker* window appears. If the model is okay, the *Status* will read *OK*. If there is something wrong, the *Status* will read *KO*. This will play a more important part in the steps later on when there are more details defined.



6. Select the clamp icon  the clamp windows appear. select the hole on bottom side of the arm which rotation point (boundary condition-1)

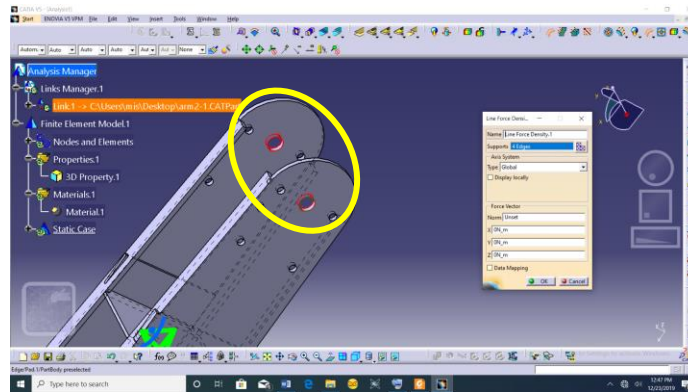


7. Select the Distributed Force icon  The *Distributed Force* window appears

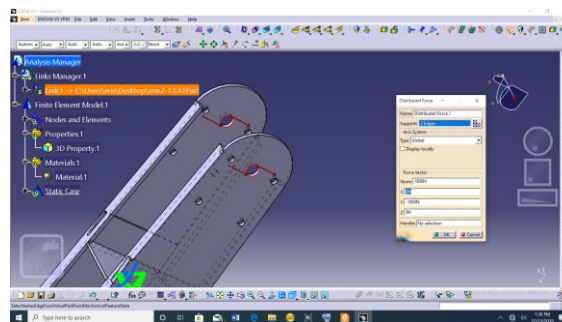
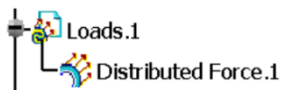


Supports	Defines the supports that the force acts on
Axis System	
Type	Defines the axis system that the force will be based upon
Display locally	Displays a local axis to help show orientation with respect to the part's local axis
Force Vector	
Norm	Defines the force in the normal direction
X	Defines the force in the X-direction
Y	Defines the force in the Y-direction
Z	Defines the force in the Z-direction
Handler	Defines the point where the forces are applied. By default, this point is at the centroid of the selection.

Select the upper hole where the intended load is applied



Set the normal force or Y to 1800N which is calculated from the total load on arm2 and approximating 1758.0N given above. Set X and Z values to be 0.0 since we do not have any applied or gravitational load exerted in these two directions and set ok. The distributed force appears under the *Loads.1* branch in the specification tree

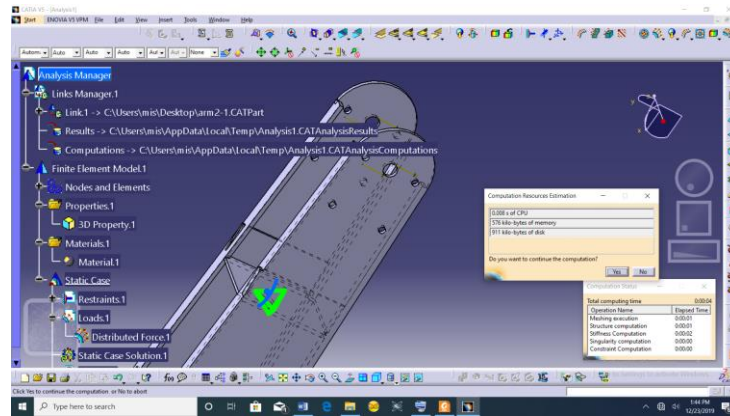


8. **Select the Compute icon.**  The *Compute* window appears



- *All* computes everything
- *Mesh only* computes the mesh only
- *Analysis case solution selection* allows to select a specific case solution to compute
- *Selection by Restraint* Computes based off of an individual constraint

9. Select *all* and select **OK**. The *Computation Resources Estimation* window appears

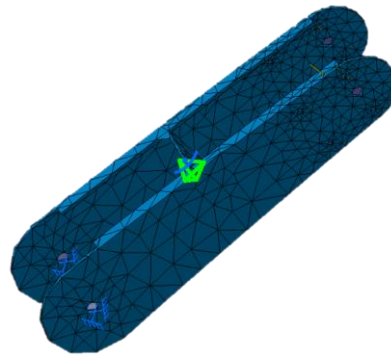


Select Yes. The analysis is computed

10. **Select the Deformation icon.**

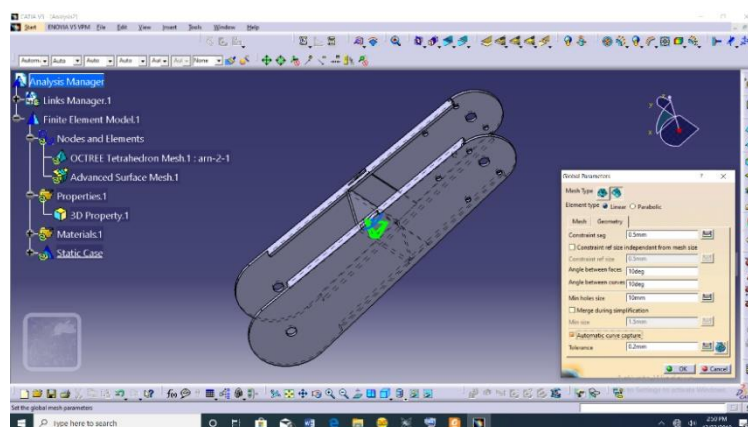


This will display the deformation of the model based on the applied restraints and loads.

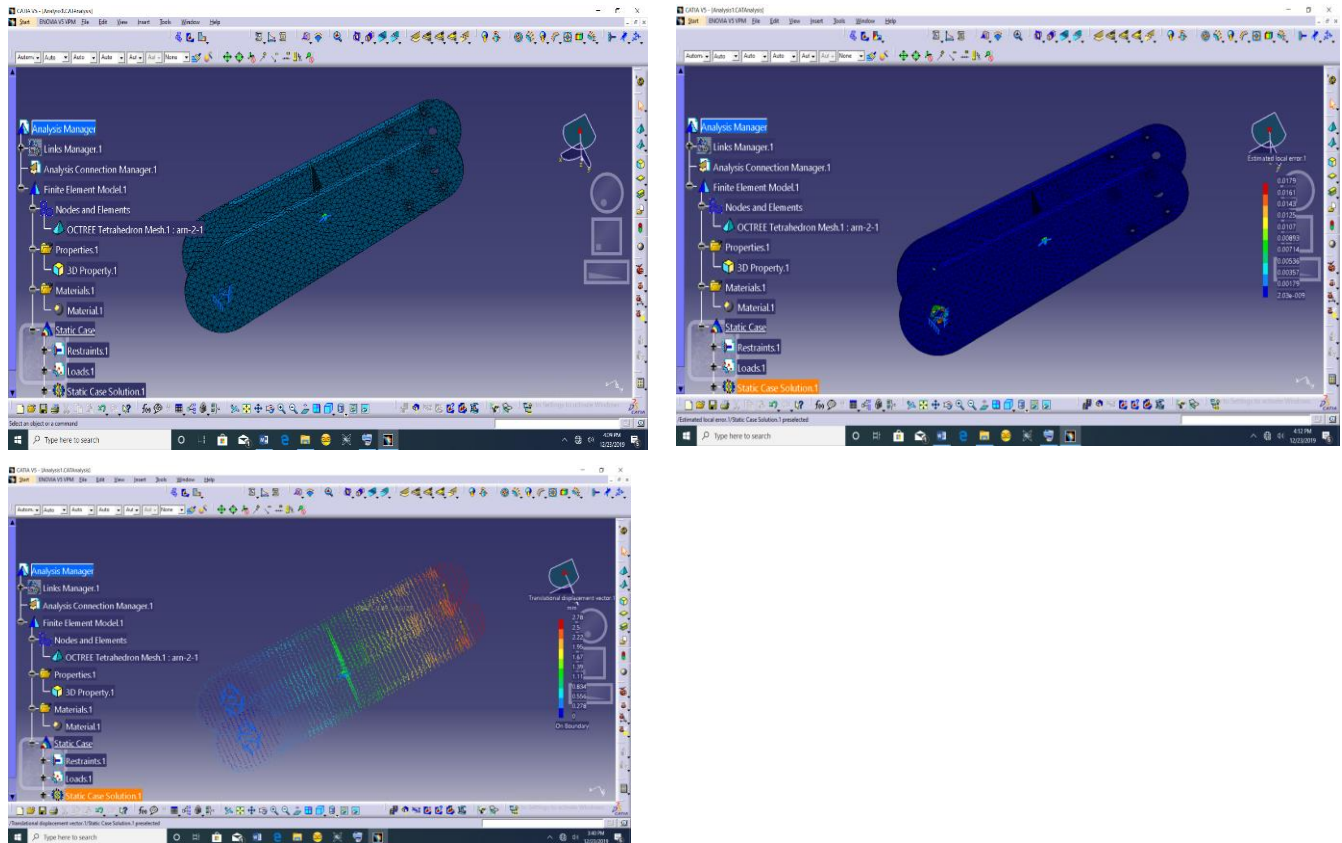


11. Double click on the OCTREE tetrahedron mesh.1 change it to advanced mesh one and set

- Mesh size to 5mm,
- Element type linear
- On geometry constraint sag 0.5mm
- Automatic curve capture 0.2mm



12. Compute the result  and see results using deformation, von misses stress and displacement icon  respectively.



As we have seen from the manipulated data the arm can resist load greater than our design one which is 1758.0Ncm. Since the FEM analysis is done for the maximum load point all the other point will also be safe. The overall result from the analysis shows the robot arm is acceptable under the given load.

3.11. Material required

To build a robot arm with five degrees of freedom the following materials are required these materials are categorized in to main four section.

Lists of material required

1. Direct material used
2. Consumables
3. Accessories
4. Tools and tackle used

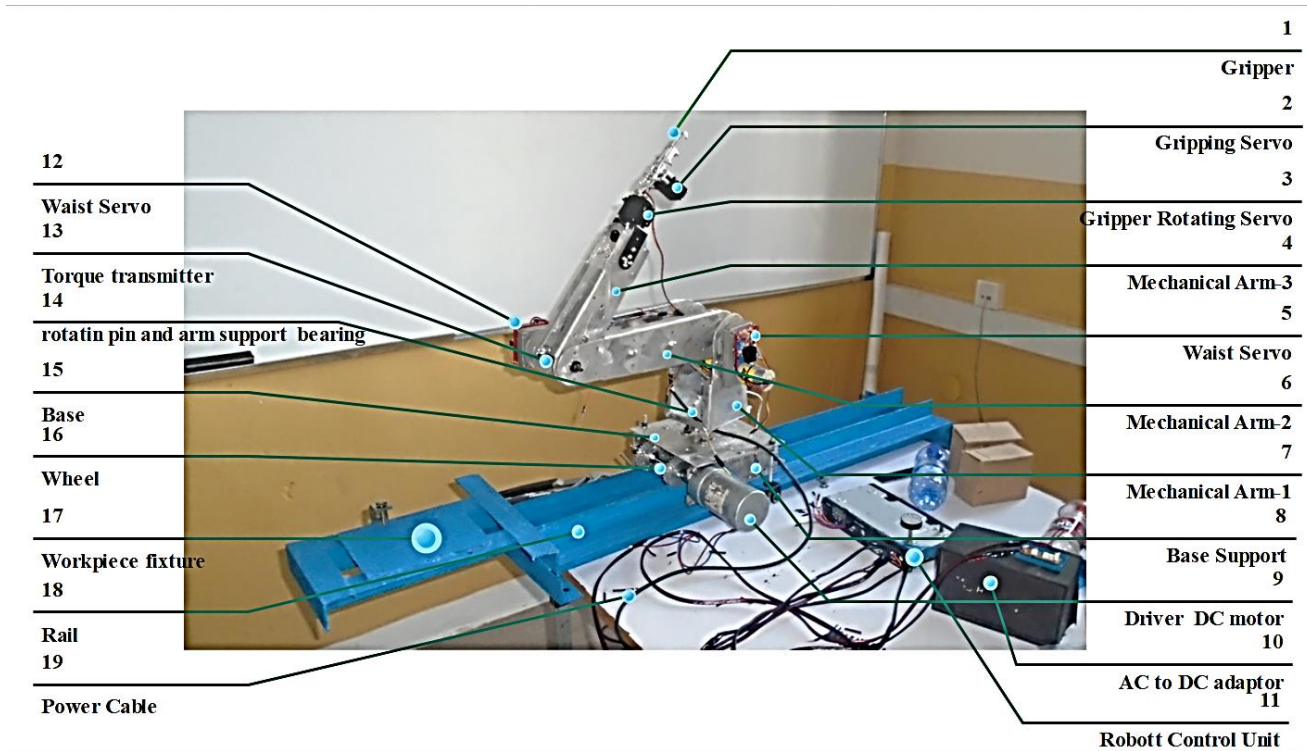


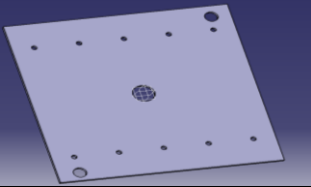
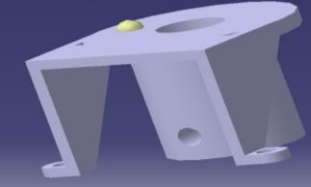
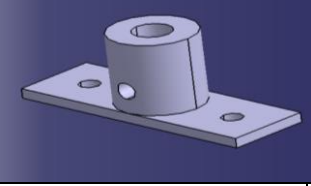
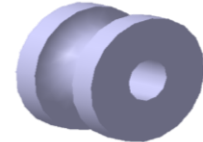
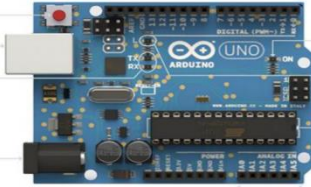
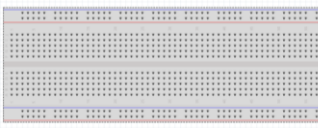
Figure 3.30 Robotics arm with name list

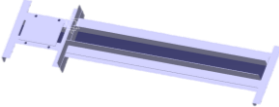
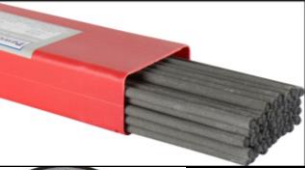
1. Direct Material used

Table 3.14 Direct material and consumable used

S. No	Lists of material	Specification	Unit	Qty	Picture	Remarks
1.	Robot arm 1	Material:- Aluminum Length: - 15cm Width: - 5cm Thickness :- 0.5cm	Pcs	1		Fabricated
2.	Robot arm 2	Material:- Aluminum Length: - 30cm Width: - 5cm Thickness :- 0.5cm	Pcs	1		Fabricated
3.	Robot arm 3	Material:- Aluminum Length: - 20cm Width: - 5cm Thickness :- 0.5cm	Pcs	1		Fabricated
4.	Robot arm 4	Material:- Aluminum Length: - 15cm Width: - 5cm Thickness :- 0.5cm	Pcs	1		Fabricated

5.	Servo motor-0	Gear material:- metal Torque:- 15 kgcm Weight:-0.24kg Dimension:-5×4×2cm Rotation angle-360deg Speed-40deg/s Power supply-5V, 1A	Pcs	2		Standard product from market
6.	Servo motor-1	Gear material:- metal Torque:- 100 kgcm Weight:-0.55kg Dimension:-10.2×6.0×3.0cm Rotation angle-270deg Speed-40deg/s Power supply-24V, 5A	Pcs	1		Standard product from market
7.	Servo motor-2	Gear material:- metal Torque:- 100 kgcm Weight:-0.55kg Dimension:-10.2×6.0×3.0cm Rotation angle-270deg Speed-40deg/s Power supply-24V, 5A	Pcs	1		Standard product from market
8.	Servo motor-3	Gear material:- metal Torque:- 100 kgcm Weight:-0.55kg Dimension:-10.2×6.0×3.0cm Rotation angle-270deg Speed-40deg/s Power supply-24V, 5A	Pcs	1		Standard product from market
9.	Servo motor-4	Gear material:- metal Torque:- 100 kgcm Weight:-0.55kg Dimension:-10.2×6.0×3.0cm Rotation angle-270deg Speed-40deg/s Power supply-24V, 5A	Pcs	1		Standard product from market
10.	Servo motor-5	Gear material:- metal Torque:- 15 kgcm Weight:-0.24kg Dimension:-5×4×2cm Rotation angle-360deg Speed-40deg/s	Pcs	1		Standard product from market
11.	Servo motor-6	Gear material:- metal Torque:- 15 kgcm Weight:-0.24kg Dimension:-5×4×2cm Rotation angle-180deg Speed-40deg/s Power supply-5V, 1A	Pcs	1		Standard product from market
12.	Driver motor DC	Gear material:- metal Torque:- 30 kgcm Weight:-0.45kg Dimension:-15×8cm Rotation angle 360deg Speed-20-48rpm Power supply-24V, 5A	Pcs	1		Standard product from market

13.	Gripper	material:- Aluminum Size:- 12cm×3cm Opening:- 0 to 5 cm	Pcs	1		Standard product from market
14.	Robot base	Material:- Aluminum Length: - 20cm Width: - 20cm Thickness :- 0.3cm	Pcs	1		Fabricated
15.	Torque transmitter and support bearing	Material:- steel size: - 4cm×3cm Thickness :- 0.2cm	Pcs	1		
16.	Torque transmitter	Material:- steel Length :- 30mm Width;-20mm	Pcs	4		
17.	Metal Wheel	Material:- Aluminum Outer diameter:- 3cm Inner diameter:- 1cm	Pcs	4		Fabricated
18.	Arduino UNO	Standard	Pcs	1		Standard product from market
19.	Potentiometer	100 ohm Continuous rotation	Pcs	7		Standard product from market
20.	Breadboard	830 holes	Pcs	1		Standard product from market
21.	Bluetooth module	HC-06	Pcs	1		Standard product from market
22.	12V- 24V DC power supply	Standard	Pcs	1		Standard product from market

23.	3V- 5V power supply	Standard	Pcs	1		Standard product from market
24.	Connecting wire	Different size	Pcs	40		Standard product from market
25.	Rail and rail support frame	Angle iron 30×30×4mm	m	8		Fabricated
26.	Bearing	Different size	Pcs	12		Standard product from market
27.	Screw/bolt nut	Different size	Pcs	120		Standard product from market
28.	Mini shaft	Length-20cm Diameter: - 1cm	Pcs	2		Standard product from market
29.	Pins	Different size	Pcs	5		
Consumables						
30.	Electrode	E6013	Pcs	10		Standard product from market
31.	Cutting disk	Dia 180, 6mm thick	Pcs	5		Standard product from market
32.	Grinding disc	Dia 180, 2.5mm thick	Pcs	2		Standard product from market
33.	Steel plate	Steel A360 Length:-15cm Width:- 5cm Thickness:- 10mm, 5mm, 4mm, 2mm	Pcs	4		Fabricated

34.	File	Different size	Pcs	3		
35.	Drill bit	Different size				

3. Accessories

Table 3.15 Accessories used

S. No	Lists of material	Specification	Unit	Qty	Remarks
1.	MIG/TIG Welding Machine	Standard	Pcs	1	ASTU
2.	380/220 AC voltage supply	Standard	Pcs	1	ASTU
3.	Computer	Desktop/ laptop	Pcs	1	ASTU
4.	MIG/TIG filler material	For steel	m	20	ASTU

4. Tools and tackle used

Table 3.16 Tools and tackle used

S. No	Lists of material	Specification	Unit	Qty	Remarks
1.	Arc welding machine	Standard	Pcs	1	ASTU
2.	Grinder Machine	Medium	Pcs	1	ASTU
3.	Drilling Machine	Medium	Pcs	1	ASTU
4.	Plate cutting machine	5mm cutting machine	Pcs	1	ASTU
5.	Wrench	No4, no6, no10	Pcs	6	ASTU
6.	Hammer	2 kg	Pcs	1	ASTU
7.	Drill bit	No-4, no-6 and no 10 HSS steel	pcs	4	ASTU
8.	CNC machine		set	1	ASTU

3.12. Standard components and their description

The component design requirement is set according to the need of the arm for MIG/TIG welding and pick and drop materials. In this part, the main basic requirements are the process of the control system and the gripper design and/or modification. Both of them have completely different requirements which consist of the physical components and their features. On the basis of these features, the components which meet the required criteria are selected. The introduction of some selected material featured are described below.

3.12.1. Arduino control board

The Arduino series circuit board can be programmed with the (Arduino Software (IDE)). The ATmega328 on the Arduino Uno comes preprogrammed with a boot loader that allows you to upload new code to it without the use of an external hardware programmer. It communicates using the original STK500 protocol.



Fig 3.31 Arduino microcontroller board (C. F. Olson, 2000)

Arduino Uno is a microcontroller board based on the ATmega328P. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started (C. F. Olson, 2000).

3.12.2. Servo Motor

Servo Motors Servo refers to an error sensing feedback control which is used to correct the performance of a system. Servo or RC Servo Motors are DC motors equipped with a servo mechanism for precise control of angular position. The Servos are used for precision positioning. They are used in robotic arms and legs, sensor scanners and in RC toys like RC helicopter, airplanes and cars.

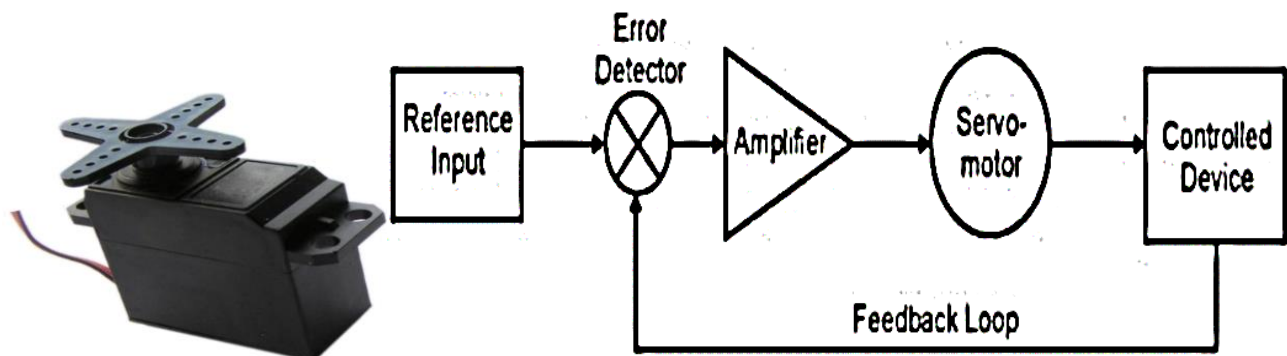


Fig 3.32 a) servo motor, b) Block diagram of a servo motor (C. F. Olson, 2000)

3.12.3. Potentiometer

A Potentiometer is a variable resistor. The two output terminals act as a fixed resistor. A movable contact called a wiper (or a slider) moves across the resistor, producing a variable resistance between the center terminals and the two sides. A potentiometer is basically a voltage divider which is used for the measurement of potential.

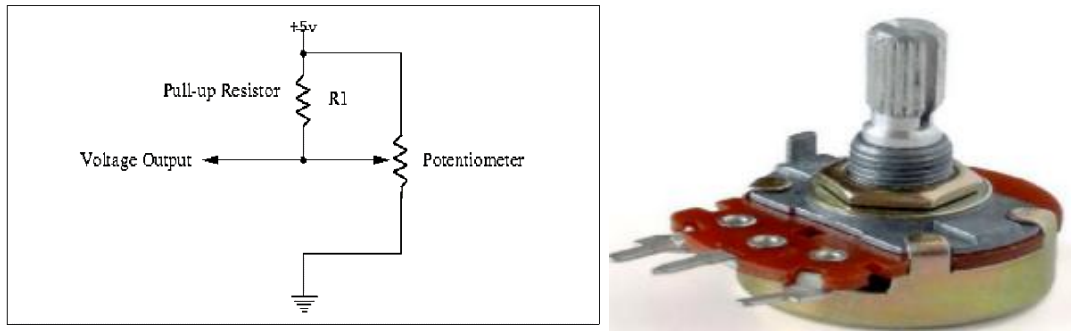


Fig 3.33 a) Circuit diagram of potentiometer b) Typical single turn potentiometer (C. F. Olson, 2000)

Potentiometers are commonly used to control electrical devices such as volume controls on audio equipment. Potentiometers which are operated by a mechanism can also be used as position transducer (C. F. Olson, 2000).

3.13. Control Design

3.13.1. Arm movement control

As mentioned on literature survey section 3.9 the mechanical arm will be controlled by a microcontroller called Arduino Mega 2560. A program is encoded using a graphical programming software for arduino board called Visuino. The encoded program will be sent or uploaded to arduino board. This program is written to control each joint servo motor using an analog input from a potentiometer. A potentiometer have three connection point which are two used for power supply and one for signal input. The potentiometer have a high and low value, as the voltage value increases on the potentiometer it sends signal to the chips of servo motor connected to the robot arm which in return start rotating the arm in clockwise direction and vice versa. The overall connection of arduino board, potentiometer and power supply generated with Fritzing software are shown below on Fig. 3.12. For easy understanding a bread board connection to the devices are shown on Fig. 3.13.

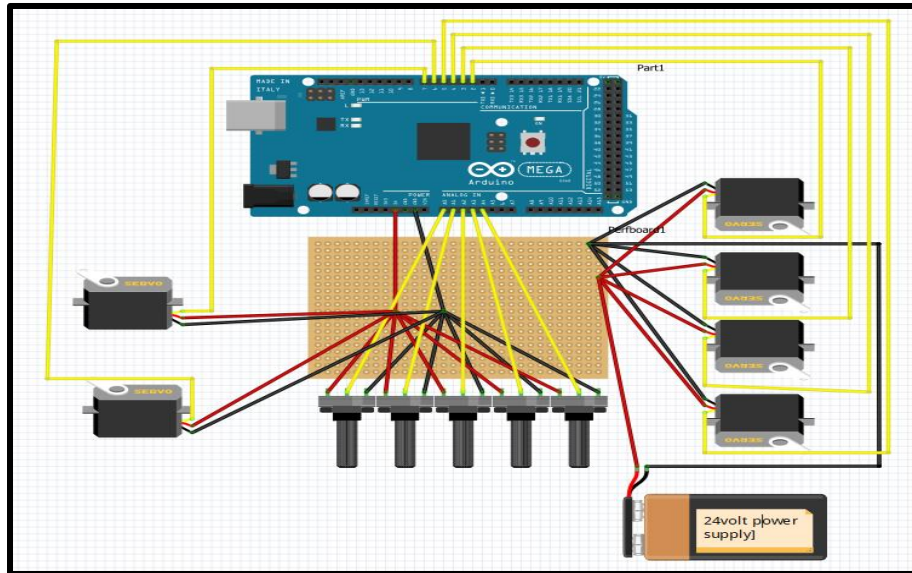


Fig 3.34- Overall connection diagram of arduino board, PCB board, servo motor, potentiometer and power supply

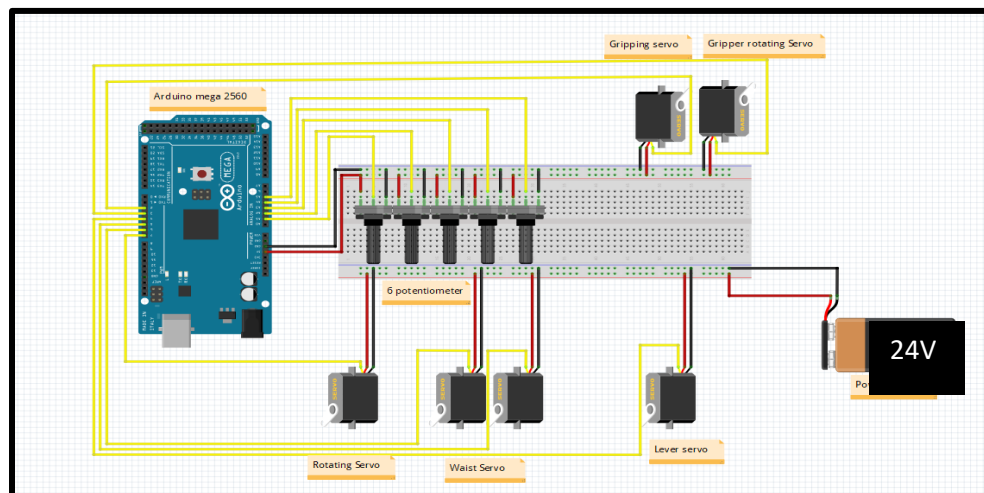


Fig 3.35 Overall connection diagram of arduino board, bread board, servo motor, potentiometer and power supply

3.13.2. Speed and direction control

The other part needs to be control is the drive DC motor which moves the arm in horizontal movement. This horizontal movement also determines the robot welding speed as well. Therefore a directly connected DC motor on the driver wheel is controlled both the direction and speed.

a. Speed control

The speed of a DC motor is controlled in three different ways

- 1) Flux control method, (Φ)
- 2) Armature rheostat control method, (IR)

3) Armature voltage control method (V)

These three parameters mathematically described as $N = \frac{V-IR}{\phi}$

Where N is RPM

V- Voltage, I-current, R-Resistance and Φ -flux

In this thesis a voltage control using a potentiometer is used.

b. Direction control

Direction of motor can be controlled by microcontroller or polarity changing switch. A DC motor with microchips are only controlled by microcontroller which are same as the servo motor used in this project. In other way DC motor without microchips only controlled by a mechanical switch designed for direction control purpose. The mechanical one is only change the polarity of the input power which result in changing the direction of the DC motor. This system of direction controller are used in the driver motor of the robot arm.

c. A limiting switch

The function of limiting switch is to limit the distance traveled by the driver motor by creating an open circuit when it gets in contact with any parts of the mechanical body of the robot arm. This device will save the robot not to go out of its rail even if not stopped by the operator and reduces accident occurrence highly. There are two limiting switches attached to the arm which prohibits forwarded and backward movement as required.

For the overall connection of the DC motor is shown in figure below.

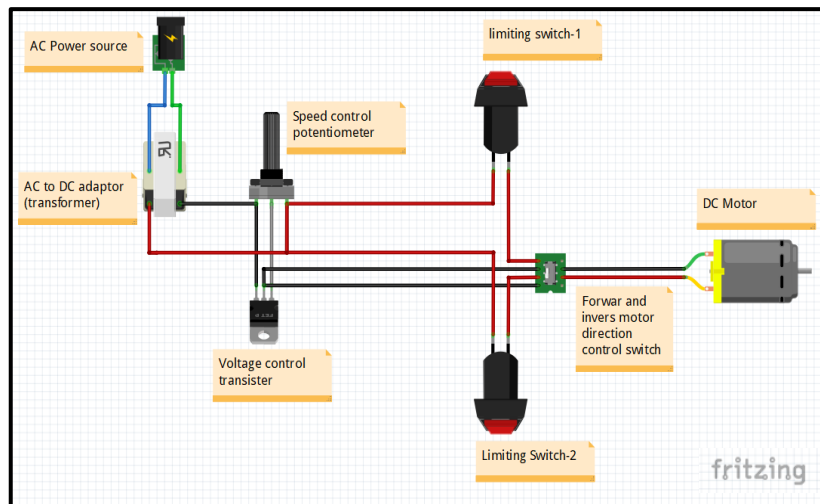


Fig 3.36 Overall connection diagram of DC driver motor, potentiometer and power supply, limiting switch

3.14. Manufacturing Process

3.14.1. Introduction part fabrication

The robot arms are a combination of mechanical and electrical parts. In this thesis, all the standard electrical parts are bought from markets. The main parts designed and manufactured are the mechanical arm, the base, shafts, driver wheel, base support, torque transmitting pin and other accessories listed on the manufacturing detail section. Parts can be manufacture with two process

1. A conventional method using ordinary manufacturing machineries like sheet metal cutter, drilling machine (manual and radial drills), grinder and hopper machines
2. CNC machineries

Part produced in executing this project are used CNC for manufacturing of parts and conventional method for modification works. For a part which needs highly accurate part like a robot arm have to be fabricated using CNC machine for better performance? The overall merits and demerits of conventional manufacturing method and CNC manufacturing method shown in Table 3.15.

Table 3.17 Manufacturing system comparison of CNC and conventional method

S.No	CNC manufacturing	Conventional Method
1.	High accuracy	Low accuracy
2.	Less time	Longer time
3.	Less cost	High cost
4.	Less available	Easy accessible
5.	Easy set up	Harder than CNC
6.	Easy operation	Harder than CNC
7.	Complex designing system	Harder than CNC

a. CNC manufacturing procedure

1. Part drawing on Auto CAD or any other compatible software and arrange it on one sheet as per the workpiece dimension as shown in fig 3.15 below



Fig 3.38 CNC Machine used

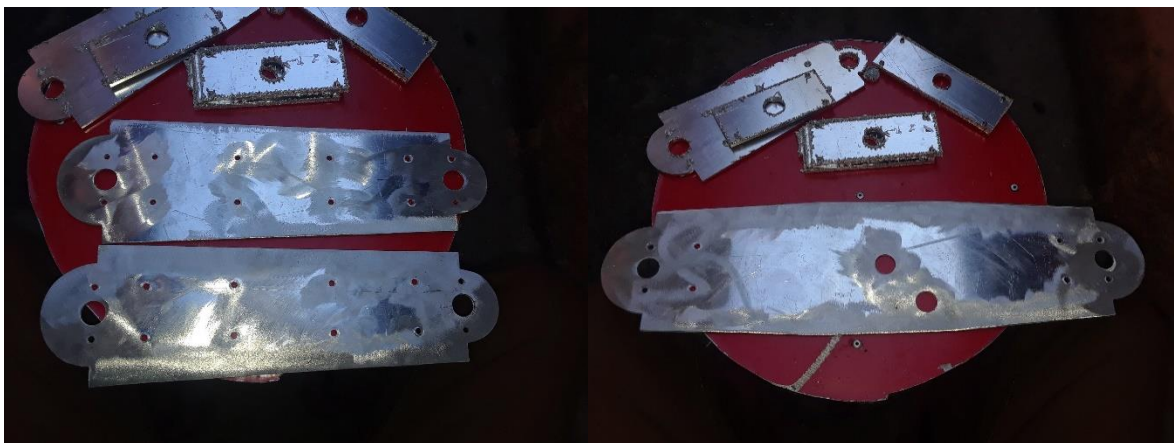
4. Start the machine operation
5. File or grind all the chips left on edges created due to the machine cutting too used



Fig 3.39 Product before and after filing

6. Bend the edge of arm-2 and arm-3, and bend arm-1 as per design

Edge bending using bending machine



A, Arm-2 before bending

B. Arm-1 and arm-3 before bending

Fig 3.40 Mechanical arm before bending

NB:-The manufacturing process details for conventional manufacturing process are attached on *appendix I* for further information.

3.14.2. Assembly Procedure

3.14.2.1. Preassembly preparation

1. Prepare a material checklist to ensure all the material are available
2. Prepare a clean and proper assembly area
3. Clean each parts
4. Prepare assembling rules and procedure to avoid rework, and material damage
5. Prepare tools and tackles required

Material check list tabulated in Table 3.16

Table 3.18 Material required check list(BOQ)

S. No	Material Description	Unit	Quantity
1.	Servo motor 100kg/cm	Pcs	4
2.	Servo motor 15kg/cm	Pcs	1
3.	Grippe with servo	Pcs	1
4.	Gripper support frame	Pcs	1
5.	Robot arm 3 pair	Pcs	1
6.	Robot arm 2 pair	Pcs	1
7.	Robot arm 1	Pcs	1
8.	M3 bolt and nut	Pcs	22
9.	M6×20 bolt and nut	Pcs	12
10.	M6×10 bolt	Pcs	24
11.	M13×200 bolt	Pcs	1
12.	M10×40 bolt and nut	Pcs	6
13.	M10×100 bolt and nut	Pcs	6
14.	Robot base	Pcs	1
15.	Wheel support	Pcs	2
16.	Wheel	Pcs	4
17.	Arduino board	Pcs	1
18.	Different data cable	Pcs	38
19.	Torque key	Pcs	4
20.	Alum bolt	Pcs	4
21.	Bearing no7	Pcs	3
22.	12-24V power supply	Pcs	1
23.	9V power supply	Pcs	1
24.	Potentiometer	Pcs	5
25.	Changing court	Pcs	1
26.	Bread board	Pcs	1
27.	Plier	Pcs	1
28.	Wrench no 4	Pcs	1
29.	Wrench no 7	Pcs	1
30.	Wrench no 10	Pcs	1
31.	Screw driver flat	Pcs	1
32.	Screw driver Philips	Pcs	1
33.	Alum key no 8	Pcs	1
34.	Grinder machine	Pcs	1
35.	Drilling machine	Pcs	1
36.	Drill bit	Pcs	1
37.	Welding machine	Pcs	1

Note: The assembling procedure can be started from different point which results a different assembly step. For this project the step followed will start from the end effector of the robot arm and follows the procedural assembling to the robot wheel.

The assembling procedure is divided in to four sub assembling and final assembling

Stage 1. End effector assembling

Step 1. Prepare gripper

Step 2. Attach servo motor-6 on gripper using 4 M3 bolt and remember to insert plastic shock absorber on each connection point (1and 2)

Step 3. Attach servomotor-5 to bottom of gripper use 2 M3 bolt and nut, (1 and 3)

Step 4. Assemble SM-5 holder and end effector support frame, use 4 M3 bolt and nut (4 and 5)

Step 5. Assemble servo motor-5 to its support, use 4 M3 bolt and nut (3 and 4)

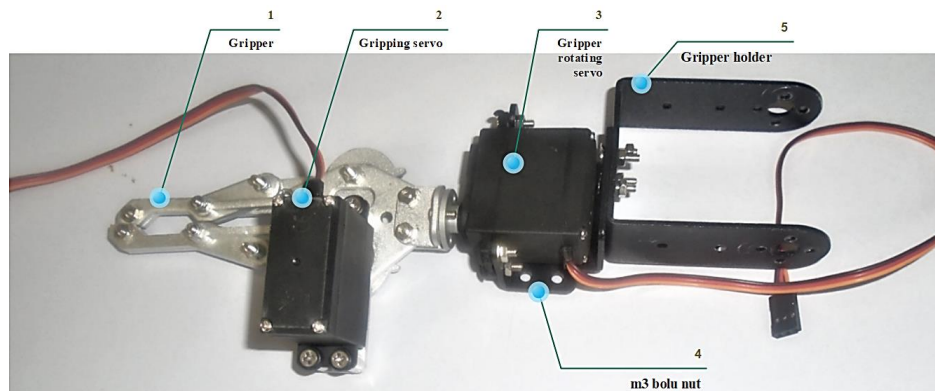


Fig 3.41 End Effector assembly

Stage 2. Robot Arm-3 and gripper assembling

Step 1. Prepare left and right side of robot arm-3 (1 and 2)

Step 2. Assemble left and right side of robot arm-3 using M10×100 bolts and nut, do not tight to end (1 and 2)

Step 3. Assemble end effector sub assemble at stage 1 use 10 M3 bolt and nut (1, 2 and 3)

Step 4. Tight all m3 bolts and nuts

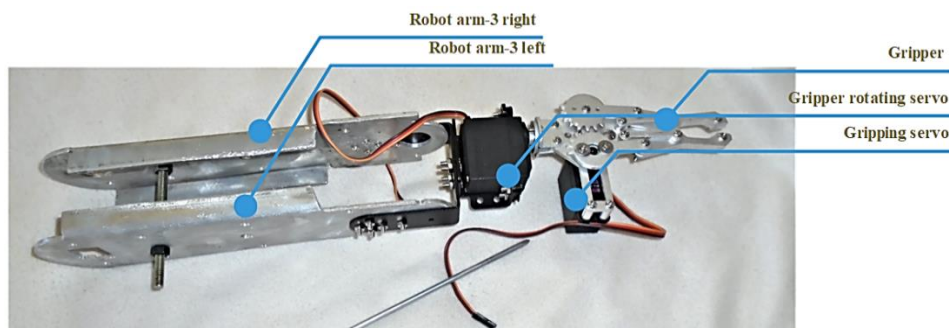


Fig 3.42 Robot arm-3 and gripper assembling

Stage 3. Robot Arm-2 and robot Arm-3 assembling

- Step 1.** Prepare left and right side of robot arm-2 (1 and 2)
- Step 2.** Attach servo motor-4 to left side of the robot arm, use 4 M6 bolt(1 and 3)
- Step 3.** Assemble torque transmission key to left and right side of robot arm 2 and robot arm 3, use 8 M6 bolt and nut and tight well (1 and 5, 2 and 5, 4 and 5)
- Step 4.** Assemble Sub assembled part at stage 3 to the servo motor attached on left side of robot arm 2 using 2 M6 bolt and nut and 1 M6 bolt and M10 alum bolt,(1, 3 and 4)
- Step 5.** Assemble left and right side of robot arm-2 using 2 M10×100, 1 M10×40 bolts and nut, do not tight to end, do not tight M10×100bolts and nuts (1, 2, 3 and 4)

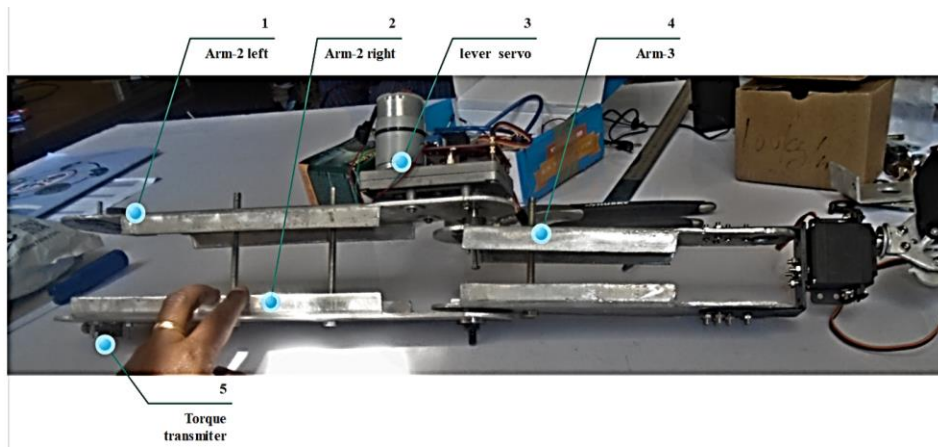


Fig 3.43 Robot arm 2 and robot arm-3 assembling

Stage 4. Robot Arm-1 and robot arm-2 assembling

In this step arm-1 and arm-2 will be assembled using two M10 bolt and nut. The other part to be assembled is simultaneous working two servo motor using four each M4 bolt and nut. The two-motor direction, speed, rotation angle and their alignment must be cautiously done for smooth operation.

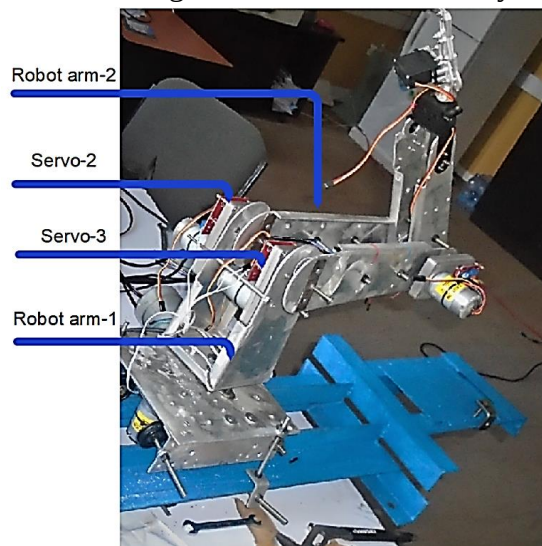


Fig 3.44 Robot arm 1 and robot arm-2 assembling

Stage 5. Robot Arm-1 and base assembling

The first step to be assembled in this stage is servo-1 which rotates the whole arm 360° using four M4 screw as shown in figure 3.24 below. Next both arm-1 and base support are connected using a horizontal support bearing and a torque transmitter, in assembling this two parts, six M10 bolts and nuts are used and tight firmly. Point to consider in this stage is same as in step-4 above. The other consideration to be taken in this stage is the direction of torque transmitter not to protect the arm movement during tightening and the overall connection is shown in Fig. 3.24.

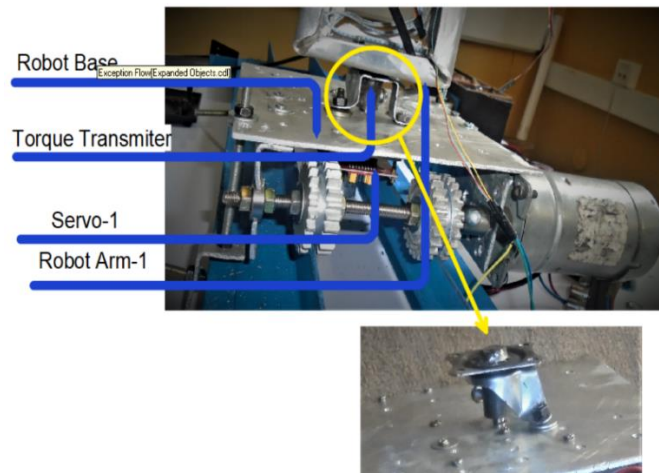


Fig 3.45 Robot arm 1 and robot base assembling

Stage 6. Base and base support, wheel and rail assembling

Before fixing the base and base support first align and assemble the drive and driven wheel on both sides of the base support to avoid work redundancy. After attaching the wheel on the support attach the base to the base support. Then align the wheel on the rail and tight firmly. Finally attach the robot guide from the base to the rail and test manually. The base and the base support are assembled using five M4 bolt and nut as shown in Fig 3.25.

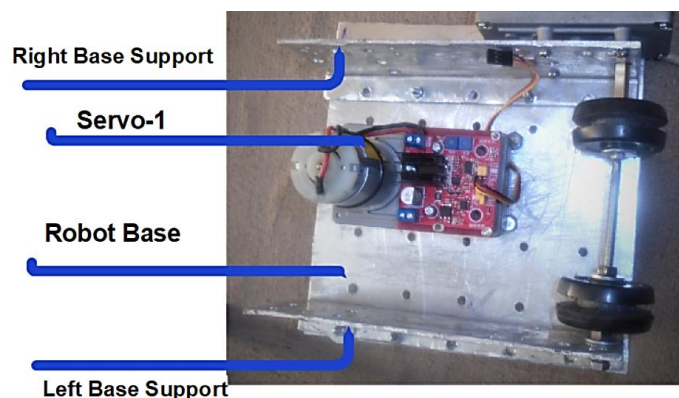


Fig. 3.46 Robot base and base support assembling

Stage 7. Robot base support and drive system and wheel assembling

The robot arm has two driver and two drive wheel system powered by a geared DC motor directly connected to the shaft of drive wheel. In assembling procedure, a proper alignment of shaft and wheel must be kept for smooth movement on the rail. Then all parts are assembled as the Fig. 3.26 shown. Foremost attention point considered in this stage is the distance between the two respective wheels must be equal with the rail guide distance and the two adjacent wheels must be aligned to travel on rail.

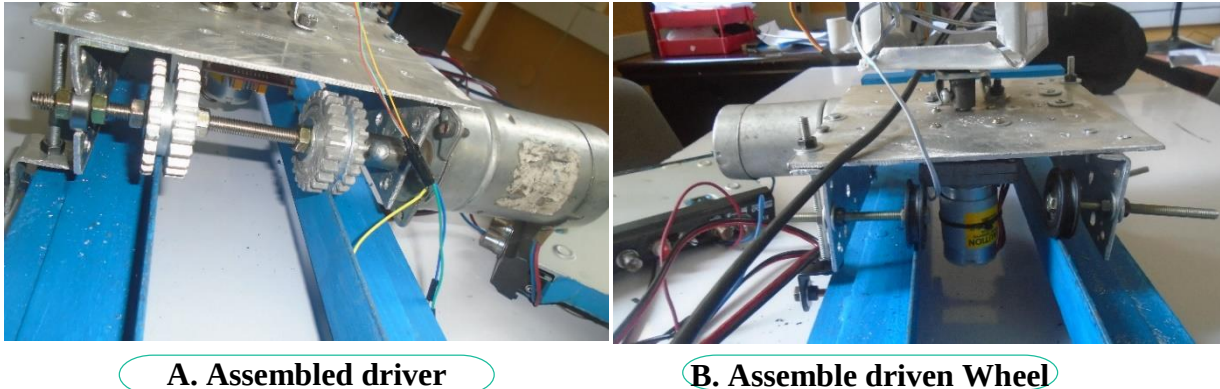


Fig 3.47 Wheel and base support assembling

Stage 8. Robot and rail assembling

This is the last stage of mechanical part assembling. In this stage the robot assembled from stage 1 to 7 are properly fixed on the guide with four wheel and tighten with a balance pin on the two-opposite corner of the base and the rail. Main function of balancing pin is to hold the robot arm in position with all its movement. In this stage the balance pin must be optimally tighten because if loosen the robot will fail down or create high wobbling and if highly tighten the drive the torque from the motor become less than the friction so that will prohibit the horizontal movement of the arm. The detail connection of wheel, rail and balancing pin will be shown on Fig. 3.27.

Stage 9. Sub assembling IIX, Electrical part installation and assembling

i. Electrical part assembling

The arduino board used mainly have three main signals which are input, output and power input and output system. The inputs are digital and analogue. Some of the digital inputs are push button, joystick, keyboard etc. some of the analogue inputs are potentiometers, and others. Let's start installing devices on arduino mega board. The step followed to assemble the device are as follow,

1. Draw the overall line diagram on Fritzing shown on fig 3.13 above on page 67
2. Attach six potentiometer of the middle leg to analogue input 0, 1, 2, 3, 4 and 5, and each one end leg to the positive terminal from arduino mega and another end to the 5V negative terminal on the arduino board.
3. Attach the servo motor

Depending on the voltage require to move the servo two types of servo are used 1, servo with 5V input which gets the power directly from the arduino board 2, servo with DC 24V from other source and control signal from arduino board. To connect the servo-1, connect the yellow or middle cable to the digital output, and the red cable to –ve terminal and the black cable to ground or +ve terminal on the arduino board. The second servo connection of control cables are same as number one except additional 24V DC power supply from outside source which is connected to its separate power supply system.

4. The final cable to be connected for program decoding is a USB cable from arduino board to computer. This cable is use to load a program to arduino board and supply power to arduino board temporarily for test.

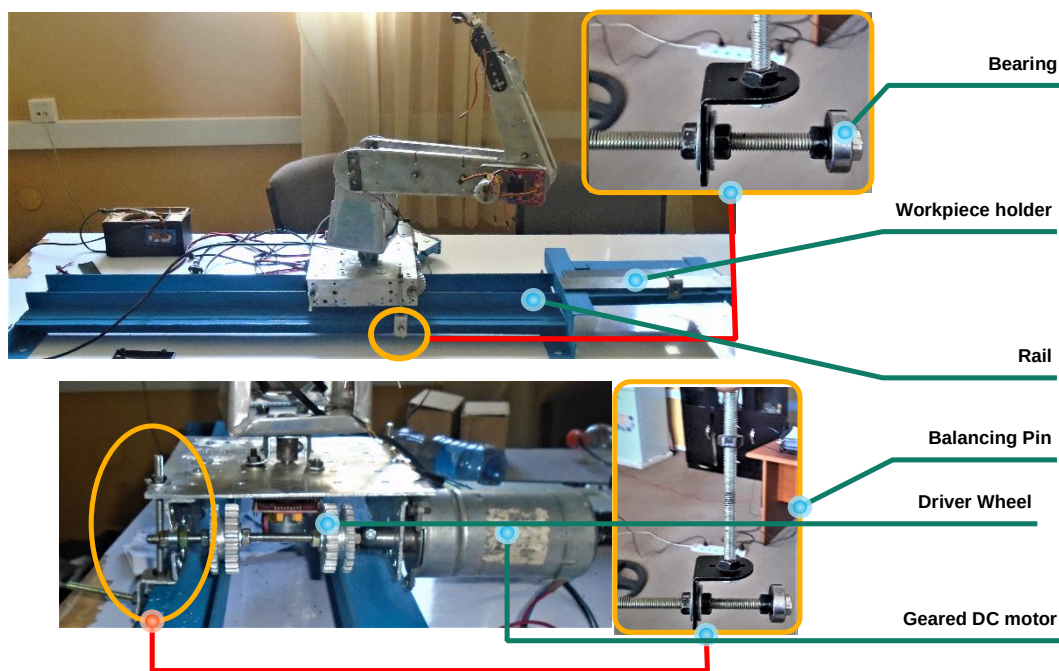


Figure 3.48 Balancing pin assembling

Stage 10. Limiting Switch assembling

After all the assembling are complete and checked the final part to assemble is limiting switch. A limiting switch is a switch which prohibits the horizontal movements of the robot arm not to pass its expected end on the rail. There are two limiting switch on the arm which is attached on the base support of the arm with one M4 bolt nut and one M10 bolt and nut. The working principles are the switch is on its normal time is close circuit as it gets pushed with any part prepared to press the circuit gets open end the motor stops as the rotation direction changed only the motor can able to rotate. As the limiting switch touches the blocker it will stop as shown in Fig. 3.28.

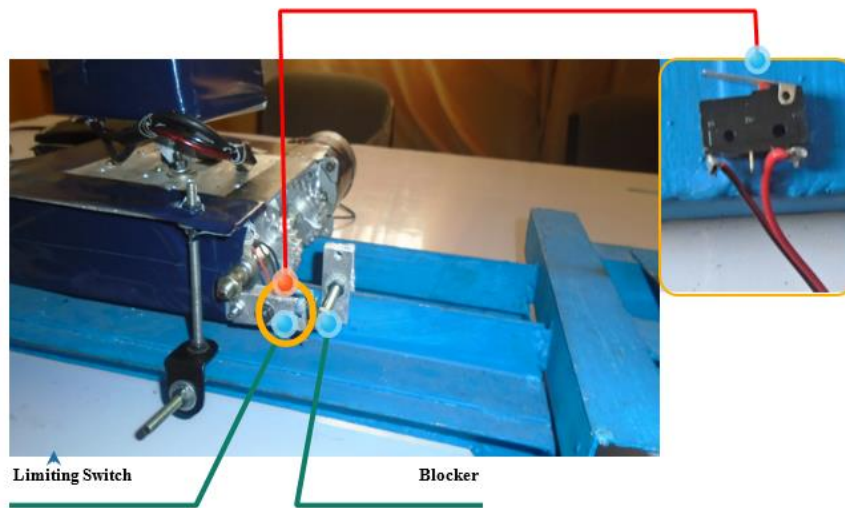


Fig 3.49 Limiting switch assembling

3.15. Software Programming parts

Before choosing the programming language to be used a person need to consider the following basic factors

1. Is the operation need higher security
2. The operation need strong programming to respond with higher accuracy
3. Is it possible to use open source or closed programming language and other parameters depending on the robot function

Considering all the above criteria and the controlling system required the programming language used is a graphical programming, an open source, easy and user friendly software called VISUINO. This software is easy to code, less security software because the purpose is only for education and all participant need to understand easily.

The programming procedures are

- i. Open Visuino software

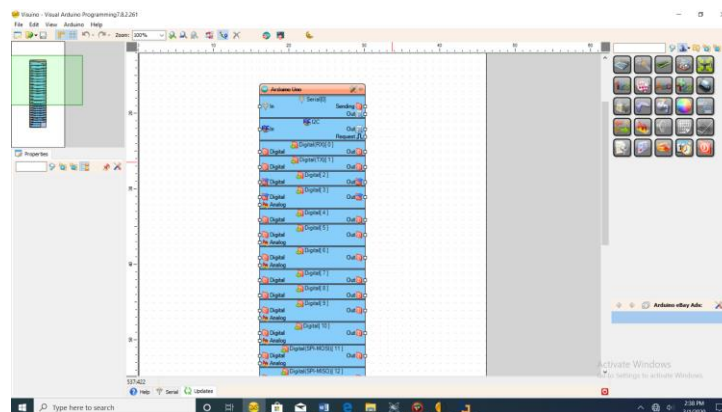


Fig 3.50 Visuino programming opening interface

- ii. Select the types of Arduino you want to use, which is Arduino Mega2560
- iii. Select and drag the device you want to be controlled by arduino board, which is “Servo motor”. The numbers of servo to be dragged will be same or greater than the number of servo to be used on the robot arm which I choose 7
- iv. Connect the output signal point of servo to the digital output pin of the board diagram of the arduino simply by clicking the pin point holding and dropping it to the pin number which the servo connected on the actual arduino board and doing same to all the servo. Simply called matching.
- v. Lastly connect the output pin of servo to one of the input pin of analogue pin on the board diagram

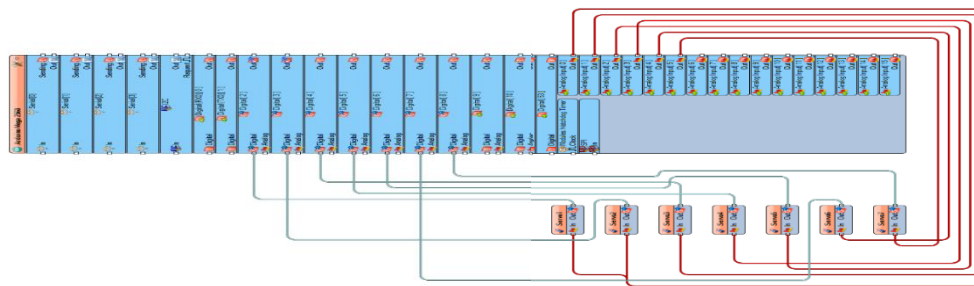


Fig 3.51 Visuino overall connection diagram

- vi. Generate code, verify and upload to arduino board

NB:-

The built code are shown on Appendix III

3.16. Automation

In this project the automated welding process are seam tracking, weld depth, welding speed, direction and degree of torch can be controlled. The seam tracking mechanism are done by a straight mechanical rail system. The seam tracking, weld speed and welding direction are controlled by a geared DC motor attached to the driver wheel. The other parameters like torch angle and torch positions are controlled by a series of servo motors attached at each joints of the robot arm. Other welding parameters like, welding voltage and current, are controlled manually by human interference. Considering all these condition the welding automation phases are done as below.

3.17.1. Phase in automation

There are three steps in welding automation process, these are: -

- **Preparation phase**
- **Welding phase**
- **Analysis phase**

Preparation phase: Before starting welding all without load test of motors, bolts and nuts, pins electrical connection, programmed software to move the arms and other mechanical and electrical parts will be checked and sated properly as per required parameters. In this phase, the operator sets up the parts to be welded, the apparatus (power source, robot, robot program, etc.) and the weld parameters, along with the type of gas and electrode wires for steel A36 with 2mm thickness and 150mm weld length. In the preparation phase process, the following parameters will be set properly.

Table 3.19 MIG welding parameter setup

Parameters	Value	Parameters	Value
Workpiece material	Steel A36	Current	60A
Material thickness and weld length	2mm and 150mm	Voltage	20 DC+
Welding type	MIG	Weld angle	60°
Gas used	CO ₂ ,	Welding gap	1.3mm
Gas flow	12-17 L/min	Welding depth	1mm
Wire thickness	0.9mm	Travel speed	0.45m/min
Wire feed speed	4.4 m/min		

NB: From standard table at appendix IV

As per the stated parameters the welding are set as follow

First attach the torch on the gripper and tight firmly using self-clamping, attach additionally on the robot arm-3 as much as possible. Simultaneously the work piece are fixed on the fixture prepared to hold it. The other preparation made here is aligning the weld direction along to the weld seam to make sure the mechanical guide of the arm will not deviate from its weld line during welding phase.

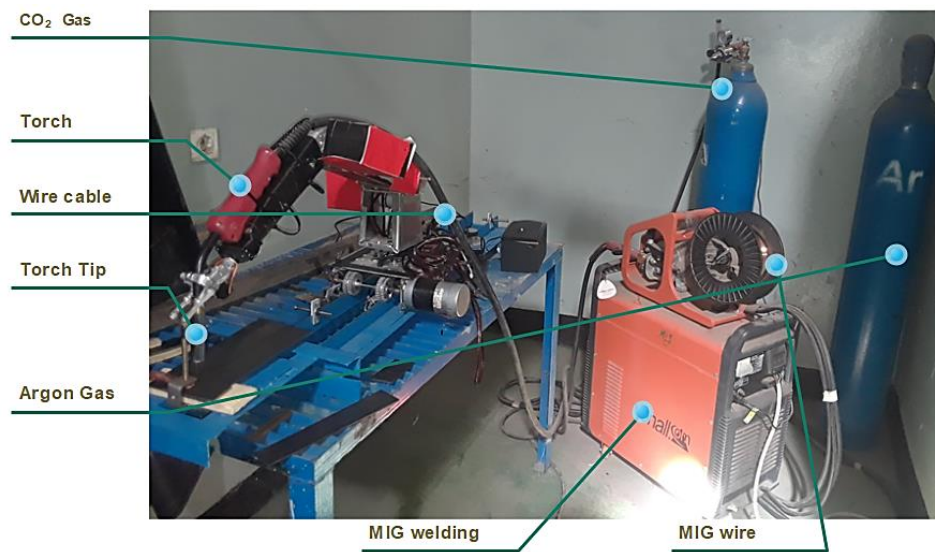


Fig 3.52 MIG welding and robot arm Setup

Welding phase: - Depending on the above weld preparation the next step performed is maintaining the weld parameters in real time. Since seam tracking mechanism is a straight rail system once it is adjusted during preparation phase it will not be additional burden at this time. Moreover, the welding speed and the torch position and weld depth are controlled by a respective potentiometer to the required parameters.



Figure 3.53 Welding time

Analysis phase: - The analysis phase is generally a post welding phase where the welding quality like penetration depth, weld line followed, seam quality and other parameters visually will be examined. The result from the analysis are shown in the result section of this thesis.

Chapter-4: Results and Discussion

4.1. Results and Discussion

In the design and fabrication process of robotic arm for arc welding different approaches are implemented to get the job done. The starts from conceptualization of the overall working principles followed by a preliminary design. The preliminary design is done using online software and a basic parameters are determined for detailed design process. Using the primary data recovered from preliminary design a detailed design of robotics arm which include the force applied, the kinematics and its control system are done. In detailed design the joint torque, arm length, numbers of joint, motor types and their respective capacity, FEM analysis of arms, modeling of the system, detail drawing and part list are prepared for fabrication and material purchase. Depending on the requirements all the materials including tools and tackles are manufactured, and/or collected and assembled accordingly tested in two stages.

From the process the following main two result are acquired

1. A multipurpose fully operated five degrees of freedom robotic arm
2. The 2mm welded steel

I. Robotic Arms

The first outcome from the thesis is a five degrees of freedom robotic arm which can move horizontally by using a geared DC motor and a five joints moving maximum of 270^0 rotationally. Even if the robot are design to perform a welding process the arm can perform additional functional like grippping, lifting and the like. The maximum distance the arm can reach is 0.80meter length wise, 0.65m width and 0.85meter vertically. With the current design feature of the arm flat, horizontal, and overhead weld can be achieved. The power source is AC 220V which are converted to DC 24V for servo motor and 9V for microcontroller.



Fig 4.1 Overall arrangements of robotic arm with MIG welding machine

The overall outcome from the projects are: -

1. Integrated control system for robot arm are developed and executed
2. A properly working program are developed and check and proved attached on appendix 12.
3. A robot arm which execute a flat MIG welding process robots are designed, fabricated tested with MIG welding process and a positive result are achieved
4. The arm primary function is a MIG flat welding process but, with a minor additional modification it can be adapted to weld horizontal and overhead welding's and work activities like gripping and lifting materials up to 0.3kg.
5. The robotic arms are tested in two step which are with and without load



Fig 4.2 Fully assembled robotics arm

5.1. Without load test

In this steps the motors are check separately and the following results are observed

Each servo motor function are well without any arm accessories, but when the accessories are attached he signal from the microcontroller and by potentiometers are highly sensitive which leads the arm to move faster and create a jerk, some arm do not move due to misalignment and loose torque transmitter. Difficulty in control of driver motor speed because of a DC motor is controlled by a volt control mechanism which highly affects to attain the exact speed required the arm to move along to the rail.

5.2. With load test

In this step the intended integral function of the arm, control system, MIG welding machine were good and positive trial weld are made. The main problems in this stage is that, the weight of the designed torch is less than the existing one, the flexibility of the torch prohibited the movements of arm-3 and arm-2, the driver motor speed is in consistent due to speed of the motor and drive system alignment. The other problem observed is that loosening of torque transmitter which let stack the arm on one position. Due to

the above-mentioned problems high vibration are created on joints and on torch as well, which highly affected the weld qualities created high spark as shown in Fig. 4.3.

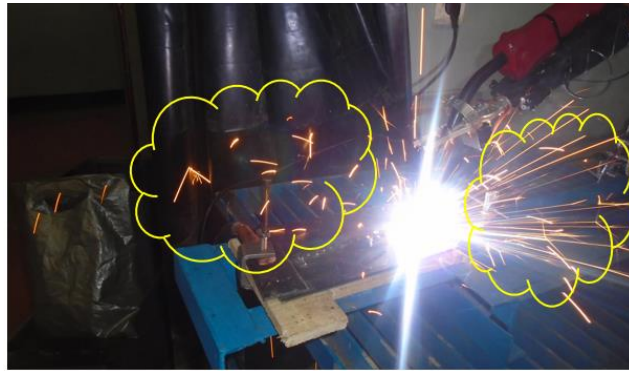


Figure 4.3 High spark during welding

II. 2mm welded steel material

Several sample welds are done by the arm, during welding process the arm can operate real time activities like positioning the arm in position, possession the weld depth, mechanically track weld line and control the weld speed even if some parameters are not attained as intended. During welding high weld spark, less weld seam tracking, jerking of arm, and difficulty in speed control are observed. Due to the above and other reasons mentioned the following problems are observed. These problems are the weld looks like spot welding than continuous one, high spark on joints are occurred, missing of weld seams are occurred as seen on Fig. 4.4 shown. As summary the point at which a proper parameter controlled a well weld penetration are observed. Considering all the complications listed on section 5.1 absent of CO₂ gas also contributed for poor welding features.

Main success from the project

1. Proper functioning of joints
2. Ease off torch positioning
3. Proper balancing of the arm
4. Suitable guiding system of robot arm
5. Good penetration if spot welding is applied than continuous one



Fig 4.4 Robot arm in welding operation

The main drawbacks shown during weld time is

1. Difficulty in controlling speed
2. High sparks
3. Over and under penetration
4. Difficulty in seam tracking
5. Movement prohibition of arm due to rigid MIG torch



Fig 4.5 High spark during welding

As a summary the overall observation on welded steel materials are described as below.

Table 4.1 Defects on weld joints

Defect observed on welded material			
S.No	Weld defect observed	Expected Reason for the defect	Remarks
1.	Deviation from weld line	Vibration on arms and misalignment on driver motor	
2.	High Porosity	High weld speed, less penetration	
3.	High slag	Absence of CO ₂	
4.	Over penetration	Vibration on arm, less weld gap	
5.	Under cut	High weld gap	
6.	Interpreted weld	High welding speed	

I. Result summary

Considering all the available resources, manufacturing process, hardship accesses of material from local markets the robot arm performance result are positive in the way that most of the intended motion is achieved. But due to the high accuracy required the predefined function of the arm which is welding steel material needs improvement in most of the parameter control aspect. Nevertheless, if consideration of resource utilized, the distance gone to design and fabricate the arm, the process parameter used during welding and as this is a start project taken it can be concluded that the result is outstanding and create a wide opportunities to learn more in the future developments of the arm.

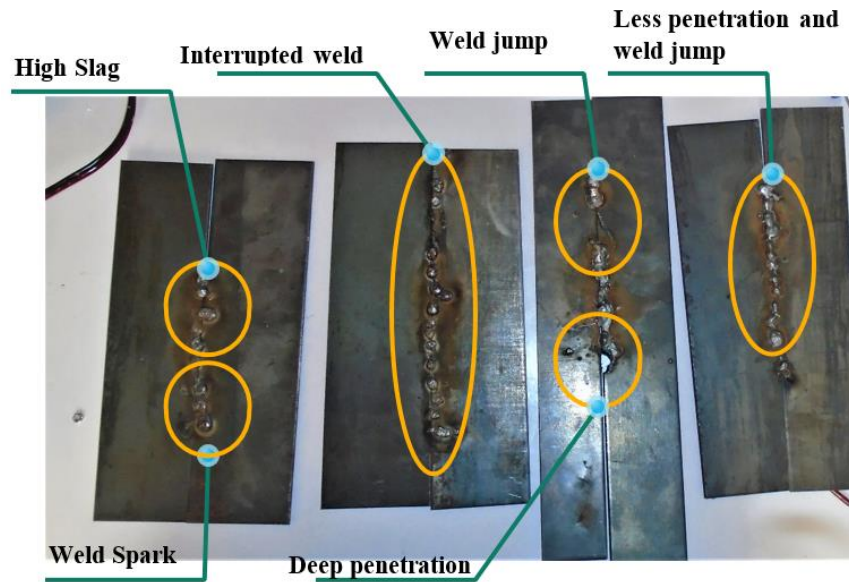


Fig 4.6 Weld defect observed

4.2. Constraint during thesis work

Constraint -1

The main problem in this thesis is to locate the position and orientation of the end effector with respect to the fixed frame of reference. In robotics, there are various ways to make a mathematical solution for locating the exact position and orientation of a rigid body in space. Depending upon the number of joints and the nature of the joint, the mathematic calculations for position and orientation of the body in space become more complex and lengthy step.

Constraint -2

In arc welding the weld quality is mainly depends on the speed of weld, welding gap, heat generated, material type (size and properties) and so on. Therefore, to get sound weld difficulty in controlling such parameters

Constraint -3

Some parts of the robot arm are designed and manufactured locally, which gives an opportunity to learn and get the material as the desired time. In the other hand some electrical parts and controlling units are not available in the country delay in supply may occur which affects the submission time of the project as well as the costs.

Constraint -4

Welding automation requires a very high accuracy in each joint movements. For better accuracy of positioning the arm accurate manufacturing processes are crucial. In doing this thesis all of mechanical parts are produced and modified locally with less precision. The lack of the production precision resulted for wobbling of the wheel and the arm.

Constraint -5

Welding speed control in welding process is the primary objective for sound weld. Herein due to the availability and its high cost the motor used is a geared DC motor which is controlled by a potentiometer modified to manipulate it. Controlling a motor with this instrument uses a voltage control process which in adverse reduce the torque also. If the torque motor reduces the load on the wheel become greater than load from the motor and stop the system. Such variation resulted constraints to attain the intended welding speed which highly affects the weld quality.

Chapter 5: Conclusion and Recommendation

5.1. Conclusion

Automating for an arc welding process in modern time production system is becoming essential. In modern welding process robot welding plays a major role in performing a complex and hazardous area work with high flexibility, productive and required quality at this time most of the welding process can be done manually by human, but working longer hour continuously and welding complex position will be impossible. Not only this keeping the productivity and quality will also be difficult. Therefore, automating a manufacturing system becomes essential to compete with the emerging markets. At this time most of automotive production industries are using mechanized production process to compete in the global markets. A country like Ethiopia have abundance labor resources which will be a pushing factor to create a manual methods of production system. Nevertheless, the fact is not what it seems, but as a country we have to follow the modernized and latest manufacturing system for more productive, high quality and compete in the global market to build an independent economy for better future of the society. To prove this simply addressing India's and China's economy with a population of more than 10 times the population of our nation can be an example. Hence, to overcome this problem rather than getting a pre-built mechanized system starting to develop a new automated manufacturing methodology and upgrading the existing production system must have to be don extensively. This project is just a startup work to address this issues.

The main aim of designing and fabricating of this robot arm is not just for fantasy, but to make an ignition point to think big and start a simple and small work. In this thesis work different engineering concept and mathematical analytic methodologies are applied from its initial conceptualization up to MIG welding process performed. In the process the work space, the arm type and length, degrees of freedom, driver motor type and specification, seam tracking mechanism, each part design and drawing, part fabrication method, assembling procedure, robot test mechanism, are determined and prepared. Moreover, each mechanical parts are fabricated using automated CNC machines and modified using conventional manufacturing equipment. Standard product like servo motor, DC motor, microcontroller boards, potentiometer, bread board and other parts are collected from market.

After manufacturing and collection step assembling is done starting from the end effector and completed by assembling the wheel with the mechanical guide or rail. In doing these different parts are changed or modified to fit properly and perform well. In parallel to mechanical assembling a control and power supply system are developed and prepared. The control system consists of microcontroller, potentiometer, bread board, data cables are some parts which are installed to the respected points. There are two types of power

supply system are used to run the whole system which are 9V DC and 24V DC adaptor to power microcontroller and motor respectively.

Several software are used to model, design, programme and prepare a documents. CAD, Catia and Fritzing are used to model and design, Visuino is used to program the microcontroller, and word, excel, Edraw, are used to prepare a document.

After all parts are assembled firmly and connected with control system a separate test are performed and remedies are taken accordingly. The final operation done is a welding test. Welding test starts with setup, in setup the following activities will be done the torch fixed on the arm and firmly tight with self-lock, the workpiece attached to it corresponding position, adjust the weld parameters like wire feed rate, gas flow rate, voltage /current, weld seam alignment are adjusted. After a proper arrangement of all parts and parameters weld test are done. During welding process, a real time parameter is controlled and adjusted. This parameter is welding speed, weld depth, and weld line. Finally, the visual inspection of weld quality is done.

As a summary the overall progress of the project is positive with the integral operation of part assembled. All joints movements motor, the mechanical guide, the arm, torque transmitters, control system and cable arrangement, programming code, power supply system, driver motor, and other main standard and locally manufactured parts are working properly.

Even if all parts are working their primary function some drawbacks are observed which affects the weld quality. These drawbacks are difficulty to control the weld speed which required additional manual support, minor jerks on joints and weld seam deviation due to motor capacity which majorly created a weld spark can be mentioned.

In this project I have acquired knowledge of basic engineering, mechanical engineering, robotics system, mathematical analysis, different manufacturing process, mechatronics principles, electrical engineering principles, software programming/coding, scientific research method and so on.

As a conclusion for a sound weld developing a robot system to make specific activities and using microcontroller speed control system and real time seam tracking mechanism will bring more reliable solution for the shortcoming seen. Due to high costs of some parts and availability of resources it is difficult to attain the intended goals which the university give more emphasis in supporting such like projects. The final conclusion is due to the nature of the project it requires multi discipline profession which need to assimilate different professionals for better and industrial level robotic work mechanization.

5.2. Recommendation

1. If the process of part fabrication methodologies are improved an ease assembling system and the joint movement accuracy can be improved

2. The torque transmitter used is modified locally which slips on some joints which increase the motor efficiency if standard parts are used
3. The seam tracking mechanism used is a simple rail type which can be affected by different joint movements and their accuracy. Therefore, if real time seam tracking mechanism is used a high quality weld seam can be achieved
4. Need to develop real time wire starter interlocking with drive motor
5. The driver motor used is a DC geared motor controlled by potentiometer for speed and relay for direction control. The difficulty here is controlling the speed of the motor without reducing its torque to drive the whole arm together. Using a motor controlled by microcontroller will be safe and sound to attain the exact speed and exact direction.
6. An interlock system is need to be developed between wire feed motor and driver motor for smooth welding operation.
7. The robotic arm concept presented in this paper still leaves a huge space for potential improvements from a variety of aspects. This includes: improving the mechanical design by adding an executive element (tool) to the final module depending on the desired application of the robotic arm; improvement of the kinematic model being used; as well as implementing a variety of new algorithms that would improve the system as a whole.
8. If multidiscipline professional participated an industrial level robotics arm can be produced
9. Since, the universities main goal is to develop the countries science and technology, more emphasis and support have to be given for project like this.

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Appendixes

Appendix-I:- Part fabrication conventional method

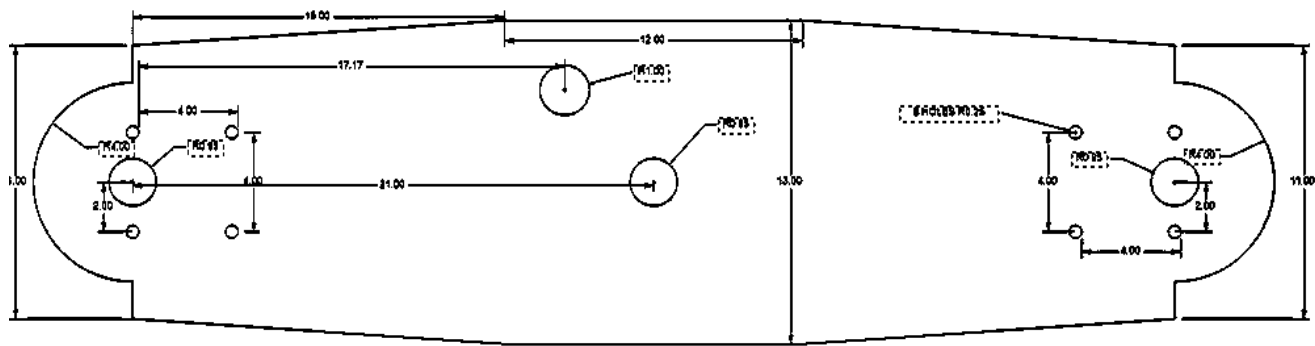
Part Name:- Robot arm-1

Part No: - FRA-1

Material type: - Aluminum

Quantity: - 1

Drawing No: - DFRA-1



Operation No	Operation Description	Machine to be used	Cutting Tool
RA1001	102mm×505mm×3mm Material preparation	Hack saw machine	
RA1002	Cutting the plate at length of 500mm	Hobbing machine	
RA1003	Tapper cutting at an angle from 100mm to 80mm from distance 190 to 0mm and from distance 190mm to 500mm	Hobbing machine	
RA1004	Cutting half circle diameter of 80mm at two end	Hobbing Machine	
RA1005	Drilling 3 holes with dia10mm @40mm, 250mm, 460mm	Drilling Machine	Drill bit M10
RA1006	Drilling 8 holes with dia5mm, @40mm, 80mm, 420mm, 460mm, 2 hole at each length 20mm far from the center	Drilling Machine	Drill bit M5
RA1007	Drilling dia20mm, @210.5mm	Drilling Machine	Drill bit M20
RA1008	Bending 90degree @distance 200 and 300mm	Bending Machine	
RA1009	Bend 20mm from left and right	Bending Machine	
RA1010	Finishing work	Grinder, sand paper	

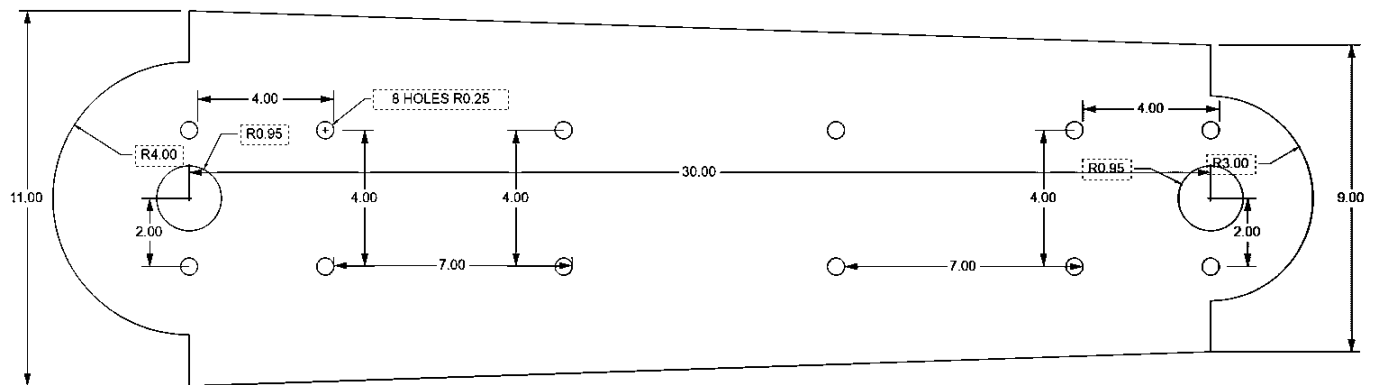
Part Name:- Robot arm-2

Part No: - FRA-2

Material type: - Aluminum

Quantity: - 2

Drawing No: - DFRA-2



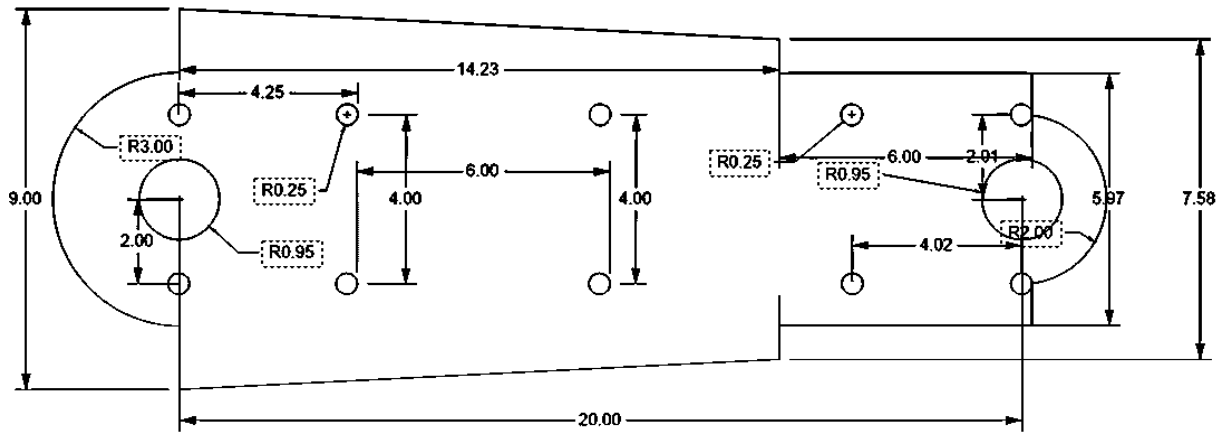
Operation No	Operation Description	Machine to be used	Cutting Tool
RA2001	85mm×375mm×3mm Material preparation	Hack saw machine	
RA2002	Cutting the plate at length of 370mm	Hobbing machine	
RA2003	Tapper cutting at an angle from 80mm to 60mm from distance 40 to 340mm	Hobbing Machine	
RA2004	Cutting half circle diameter of 80mm at @40mm	Hobbing Machine	
RA2005	Cutting half circle diameter of 60mm at @340mm	Hobbing Machine	
RA2006	Drilling 2 holes with dia10mm @40mm, 340mm	Drilling Machine	Drill bit M10
RA2007	Drilling 12 holes with dia5mm, @40mm, 80mm,120mm, 200mm,270mm,340mm, 2 hole at each length 20mm far from the center	Drilling Machine	Drill bit M5
RA2008	Bend 20mm from left and right	Bending Machine	
RA2009	Finishing work		

Part Name:- Robot arm-3 left

Part No: - FRA-4

Material type: - Aluminum Quantity: - 1

Drawing No: - DFRA-3



Operation No	Operation Description	Machine to be used	Cutting Tool
RA3001	65mm×255mm×3mm Material preparation	Hack saw machine	
RA3002	Cutting the plate at length of 250mm	Hobbing machine	
RA3003	Tapper cutting at an angle from 60mm to 40mm from distance 30 to 162.5mm	Hobbing Machine	
RA3004	Preparing 60mm×60mm from distance 162.5 to 220.5 for motor support	Hobbing machine	
RA3005	Cutting half circle diameter of 60mm at @30mm	Hobbing Machine	
RA3006	Cutting half circle diameter of 40mm at @230mm	Hobbing Machine	
RA3007	Drilling 2 holes with dia10mm @30mm, 230mm	Drilling Machine	Drill bit M10
RA3008	Drilling 10 holes with dia5mm, @30mm, 70mm,130mm, 190mm,230mm, 2 hole at each length 20mm far from the center	Drilling Machine	Drill bit M5
RA3009	Bend 20mm from left and right	Bending Machine	
RA3010	Finishing work		

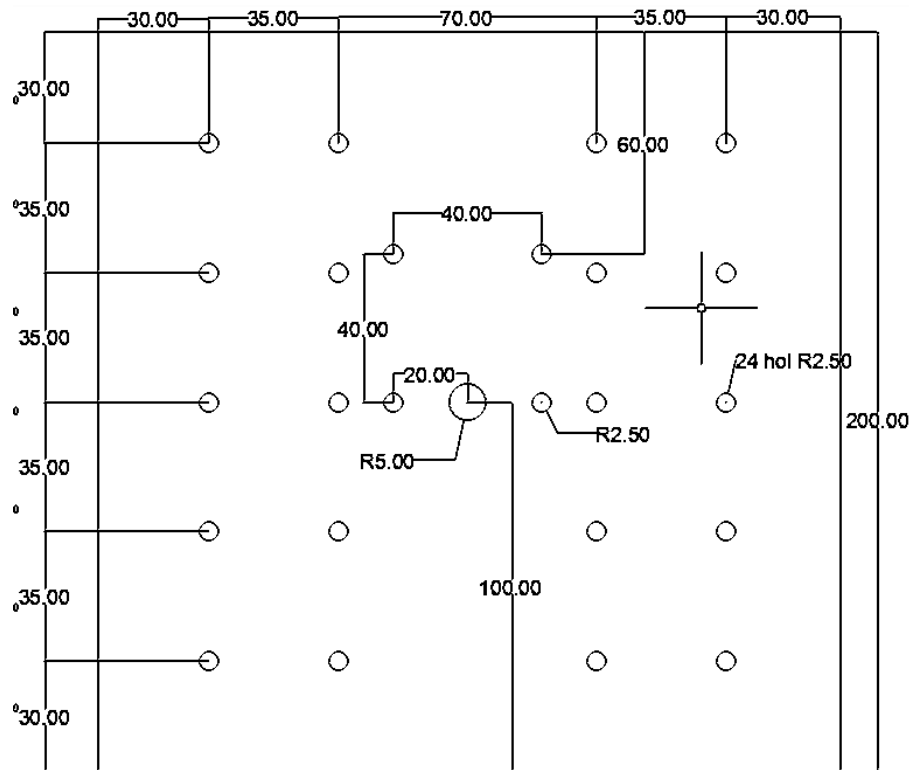
Part Name: - Robot arm-3 Right

Part No: - FRA-6

Material type: - Aluminum

Quantity: - 1

Drawing No: - DFRA-4



Operation No	Operation Description	Machine to be used	Cutting Tool
RB5001	200mm×200mm×3mm Material preparation	Hack saw machine	
RB5002	Cutting the plate at length of 200mm	Sheet metal cutter	
RB5003	Drilling circle diameter of 20mm at @ center		
RB5004	Drilling 10 holes with dia 5mm @30mm, from the edge on both side (five holes each side)	Drilling Machine	Drill bit M10
RB5005	Drilling 10 holes with dia 5mm @65mm, from the edge on both side (five holes each side)	Drilling Machine	Drill bit M5
RB5006	Drilling 2 holes with dia 5mm @20mm, from the center	Bending Machine	
RB5007	Drilling 2 holes with dia 5mm @40mm, from the center		
RB5008	Finishing work		

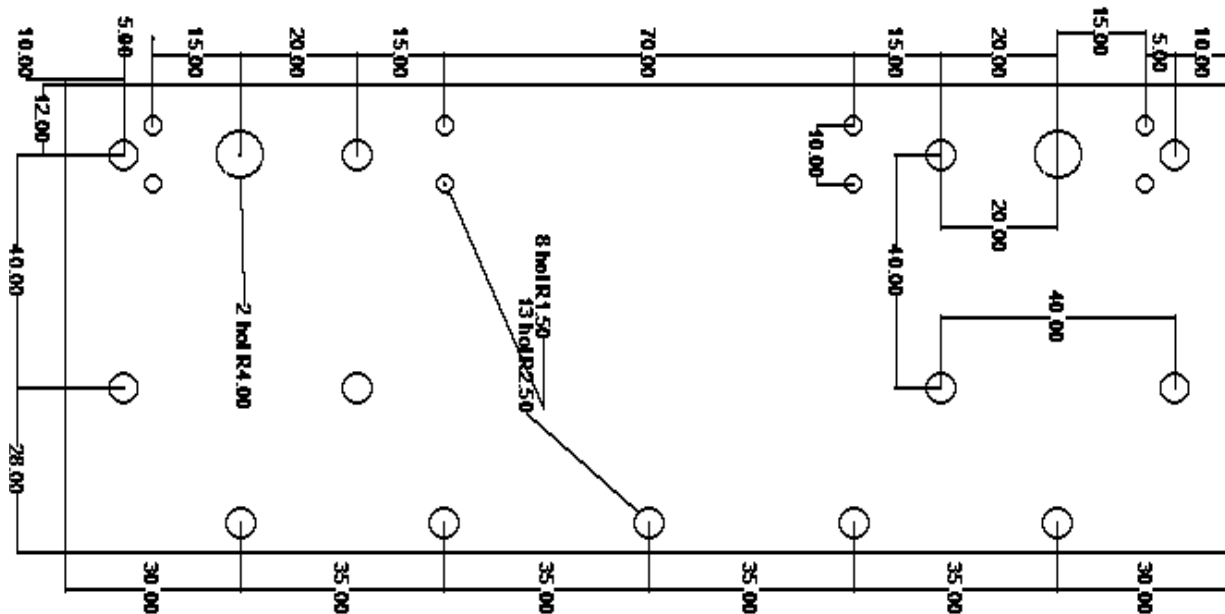
Part Name: - Robot arm base support

Part No: - FRA-9

Material type: - Aluminum

Quantity: - 2

Drawing No: - DRABS0001



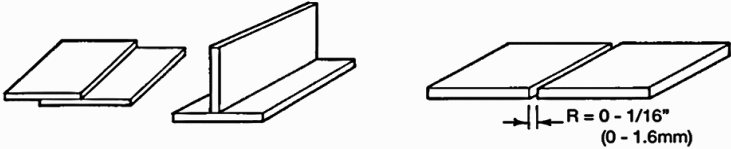
Operation No	Operation Description	Machine to be used	Cutting Tool
RBS6001	70mm×200mm×3mm Material preparation	Hack saw machine	
RBS6002	Cutting the plate at length of 200mm	Hobbing machine	
RBS6003	Drill 5 holes diameter of 5mm @ 10mm from edge	Hobbing Machine	
RBS6004	Drilling 4 holes with dia 5mm @28mm	Drilling Machine	Drill bit M10
RBS6005	Drilling 4 holes with dia5mm, @68mm,	Drilling Machine	Drill bit M5
RBS6006	Drilling 1 holes with dia5mm, @30mm and 68mm, Drilling 1 holes with dia5mm, @170mm and 68mm	Drilling Machine	
RBS6007	Bending 90 degree @ 20mm	Bending Machine	
RBS6008	Finishing work		

Appendix II: - MIG welding Standard data table from machine manuals

General Welding Guidelines

Welding Guidelines for Carbon and Low Alloy Steel

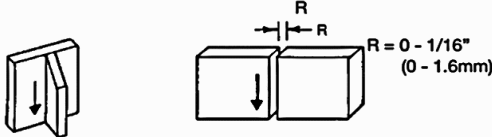
Welding Guidelines for Carbon and Low Alloy Steel Short-Circuiting Transfer — Horizontal Fillets and Flat Butt Joints

CTWD ⁽¹⁾ : 1/2" (13mm) Gas: 100% CO ₂ Gas flow: 25 to 35 cfh (12 to 17 L/min.)															
Plate Thickness - (mm)	24 ga (0.6)		20 ga (0.9)		16 ga (1.5)		14 ga (2)		12 ga (3)		10 ga (4)		3/16" (5)		1/4" (6)
Electrode Dia. - in. (mm)	0.025 (0.6)	0.030 (0.8)	0.030 (0.8)	0.035 (0.9)	0.030 (0.8)	0.035 (0.9)	0.030 (0.8)	0.035 (0.9)	0.030 (0.8)	0.035 (0.9)	0.030 (0.8)	0.035 (0.9)	0.045 (1.1)	0.045 (1.1)	0.045 (1.1)
WFS - in./min (M/min.)	100 (2.5)	75 (1.9)	125 (3.2)	100 (2.5)	175 (4.4)	150 (3.8)	225 (5.7)	175 (4.4)	275 (7.0)	225 (5.7)	300 (7.6)	250 (6.4)	125 (3.2)	150 (3.8)	200 (5.0)
Amps (Approximate)	35	35	55	80	80	120	100	130	115	160	130	175	145	165	200
Travel Speed - in./min (M/min.)	10 (0.25)	10 (0.25)	14 (0.35)	13 (0.33)	13 (0.33)	20 (0.50)	18 (0.45)	18 (0.45)	20 (0.50)	20 (0.50)	17 (0.43)	20 (0.50)	18 (0.45)	15 (0.38)	13 (0.33)
Voltage ⁽²⁾ (DC+)	17	17	18	18	19	19	20	20	21	21	22	22	18-20	19-21	20-22

⁽¹⁾ Contact Tip to Work Distance

⁽²⁾ Decrease 2 volts for Argon/CO₂ blend.

Welding Guidelines for Carbon and Low Alloy Steel Short-Circuiting Transfer — Vertical Down Fillets and Square Butt Joints

CTWD ⁽¹⁾ : 1/2" (13mm) Gas: 100% CO ₂ Gas flow: 25 to 35 cfh (12 to 17 L/min.)											
Plate Thickness - (mm)	24 ga (0.6)		18 ga (1)		14 ga (2)		10 ga (4)			3/16" (5)	1/4" (6)
Electrode Dia. - in. (mm)	0.025 (0.6)	0.030 (0.8)	0.030 (0.8)	0.035 (0.9)	0.030 (0.8)	0.035 (0.9)	0.030 (0.8)	0.035 (0.9)	0.045 (1.1)	0.045 (1.1)	0.045 (1.1)
WFS - in./min (M/min.)	100 (2.5)	75 (1.9)	150 (3.8)	125 (3.2)	225 (5.7)	175 (4.4)	300 (7.6)	250 (6.4)	125 (3.2)	150 (3.8)	200 (5.0)
Amps (Approximate)	35	35	70	100	100	130	130	175	145	165	200
Travel Speed - in./min (M/min.)	10 (0.25)	10 (0.25)	15 (0.38)	19 (0.48)	20 (0.50)	20 (0.50)	20 (0.50)	20 (0.50)	20 (0.50)	17 (0.43)	17 (0.43)
Voltage ⁽²⁾ (DC+)	17	17	18	18	20	20	22	22	19	20	21

⁽¹⁾ Contact Tip to Work Distance

⁽²⁾ Decrease 2 volts for Argon/CO₂ blend.

Data from Lincoln electric

Appendix III: - Code for robot arm driver for arduino MEGA

```
#define VISUINO_ARDUINO_MEGA
#include <OpenWire.h>
#include <Mitov.h>
#include <Mitov_FormattedSerial.h>
#ifndef VISUINO_ESP32
#include <Servo.h>
#endif // VISUINO_ESP32
#include <Mitov_Servo.h>
// Arduino Board Declarations
namespace BoardDeclarations
{
Mitov::ArduinoAnalogInputChannel<0> ArduinoAnalogInputChannel_0;
Mitov::ArduinoAnalogInputChannel<1> ArduinoAnalogInputChannel_1;
Mitov::ArduinoAnalogInputChannel<2> ArduinoAnalogInputChannel_2;
Mitov::ArduinoAnalogInputChannel<3> ArduinoAnalogInputChannel_3;
Mitov::ArduinoAnalogInputChannel<4> ArduinoAnalogInputChannel_4;
} // BoardDeclarations
// Declarations
namespace Declarations
{
Mitov::MitovServo<2, 200, 4500> Servo1;
Mitov::MitovServo<3, 544, 2400> Servo2;
Mitov::MitovServo<4, 544, 2400> Servo3;
Mitov::MitovServo<5, 544, 2400> Servo4;
Mitov::MitovServo<6, 544, 2400> Servo5;
Mitov::MitovServo<7, 544, 2400> Servo6;
} // Declarations
// Pin Call Declarations
namespace PinCalls
{
void PinCallerReceive1( void *_Data );
void PinCallerReceive2( void *_Data );
void PinCallerReceive3( void *_Data );
void PinCallerReceive4( void *_Data );
void PinCallerReceive5( void *_Data );
} // PinCalls
// Pin Call Implementations
{
void PinCallerReceive1( void *_Data )
{
Declarations::Servo1.InputPin_o_Receive( _Data );
}
void PinCallerReceive2( void *_Data )
{
Declarations::Servo2.InputPin_o_Receive( _Data );
}
void PinCallerReceive3( void *_Data )
{
Declarations::Servo3.InputPin_o_Receive( _Data );
}
}
```

```

void PinCallerReceive4( void *_Data )
{
    Declarations::Servo4.InputPin_o_Receive( _Data );
}
void PinCallerReceive5( void *_Data )
{
    Declarations::Servo5.InputPin_o_Receive( _Data );
    Declarations::Servo6.InputPin_o_Receive( _Data );
}
} // PinCalls
namespace ComponentsHardware
{
void SystemUpdateHardware()
{
}
} // ComponentsHardware
//The setup function is called once at startup of the sketch
void setup()
{
    BoardDeclarations::ArduinoAnalogInputChannel_0.OutputPin.SetCallback( PinCalls::PinCallerReceive1 );
    BoardDeclarations::ArduinoAnalogInputChannel_1.OutputPin.SetCallback( PinCalls::PinCallerReceive2 );
    BoardDeclarations::ArduinoAnalogInputChannel_2.OutputPin.SetCallback( PinCalls::PinCallerReceive3 );
    BoardDeclarations::ArduinoAnalogInputChannel_3.OutputPin.SetCallback( PinCalls::PinCallerReceive4 );
    BoardDeclarations::ArduinoAnalogInputChannel_4.OutputPin.SetCallback( PinCalls::PinCallerReceive5 );
    BoardDeclarations::ArduinoAnalogInputChannel_0.SystemInit();
    BoardDeclarations::ArduinoAnalogInputChannel_1.SystemInit();
    BoardDeclarations::ArduinoAnalogInputChannel_2.SystemInit();
    BoardDeclarations::ArduinoAnalogInputChannel_3.SystemInit();
    BoardDeclarations::ArduinoAnalogInputChannel_4.SystemInit();
    BoardDeclarations::ArduinoAnalogInputChannel_0.SystemStart();
    BoardDeclarations::ArduinoAnalogInputChannel_1.SystemStart();
    BoardDeclarations::ArduinoAnalogInputChannel_2.SystemStart();
    BoardDeclarations::ArduinoAnalogInputChannel_3.SystemStart();
    BoardDeclarations::ArduinoAnalogInputChannel_4.SystemStart();
    Declarations::Servo1.SystemStart();
    Declarations::Servo2.SystemStart();
    Declarations::Servo3.SystemStart();
    Declarations::Servo4.SystemStart();
    Declarations::Servo5.SystemStart();
    Declarations::Servo6.SystemStart();
}
// The loop function is called in an endless loop
void loop()
{
    unsigned long A_Current_Microseconds = micros();
    BoardDeclarations::ArduinoAnalogInputChannel_0.SystemLoopBegin( A_Current_Microseconds );
    BoardDeclarations::ArduinoAnalogInputChannel_1.SystemLoopBegin( A_Current_Microseconds );
    BoardDeclarations::ArduinoAnalogInputChannel_2.SystemLoopBegin( A_Current_Microseconds );
    BoardDeclarations::ArduinoAnalogInputChannel_3.SystemLoopBegin( A_Current_Microseconds );
    BoardDeclarations::ArduinoAnalogInputChannel_4.SystemLoopBegin( A_Current_Microseconds );
}

```