ETEC 43018 – Capstone Project Report

MANIPULATOR DESIGN AND DEVELOPMENT FOR OFFLINE ROBOT PROGRAMMING PLATFORM

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Abstract

The report documents the conceptualization, design, fabrication, and control of a 4 degree of freedom articulated robot for offline platform. This report covers everything from designing a robot manipulator to analysing a prototype. The main purpose of doing this was to create a robot manipulator that could be used for an offline platform suitable for small industry. Many of today's factories are being automated. The study is based on small-scale inventors. Not only a robot manipulator design but also an outline of a white offline platform to control it is included in this study. Technical tools such as ROS, Arduino, PlC were used for this study.

Keywords

- Arduino
- C+
- Kinematics
- Moveit
- Offline Programming Platform
- Python
- Robot manipulator
- Robot Operating System
- Solidworks
- Teach pendent
- Universal Robot Description Format

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List of Abbreviations

CAD - computer-aided design

DOF – degree of freedom

FK – forward kinematic

HMI – human machine interface

IK – Invers kinematic

PLC – programable logic controller

ROS – Robot Operating system

URDF - Universal Robot Description Format

Statement of Original Authorship

The work contained in this thesis has not been previously submitted to meet requirements for an award at this or any other higher education institution. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made.

Signature: ______________________

Date: 30-06-2022

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Chapter 1: Introduction

1.1 BACKGROUND

The use of robot manipulator is very popular nowadays. This is because robot manipulators are used for many manufacturing and research processes in the industry these days. This is due to the reduction in human labour and the ease of work. However, the initial start-up cost of a current robot manipulator has been a problem for some businesses. This challenge has greatly affected small factory owners. The cost of existing systems and the inherent processes that can make them very difficult to utilize. They also sometimes find it difficult to find systems that are suitable for the intrinsic processes that take place in small factories. Systems with the ability to modify processes according to their needs will be their basic need. Because they have to buy separately the robot manipulator, they need to do the small tasks they have. It is also very difficult to operate and maintain such many machines. The solution here is to have a mechanism that can easily make changes. A system that can make such changes and a robot manipulator will answer many their problems. There should be a solution that is very flexible and easy to handle.

The high cost of these types of systems today and the need for knowledge and technology to operate them are major problems for industrialists. Most robot controlling platforms require very advanced hardware and software components. This is because the accuracy of the tools used in handling such a program is very important. So all the accessories used for this are very expensive. Used hardware also costs more to buy. Otherwise, hardware often does not work in real-time. Thus, building them using UNIX/LiNUX-like control systems is very difficult. Here compare old reports and existing systems and focus on their shortcomings and aspects that need to be developed. This was done mainly targeting small factories. But this was intended to make it usable without problems for small factories as well as large factories. Here they have a huge advantage and will be very much in tune with the current global situation.

1.2 CONTEXT

A key component of industrial enterprise automation is the use of robotic systems with mechanical handling and control systems. In industry, robots are used for a variety of operations. By this time, the technology was a pervasive part of the work world. But most of these robots are very expensive. These control systems are also expensive, so the cost of control and handling is very high. Industry owners are also facing this dilemma. Parties to this problem include factory managers who require the use of robots, as well as manufacturers of small-scale robots locally.

When purchasing an existing robotic manipulator, in most cases they are specifically designed for a routine process. Because of this, the device can only be used for the same process. The control systems used for handling are also not allowed to be differentiated due to their own proprietary systems. Therefore, turning to other devices for different activities is a big financial problem. Also, most of the control systems currently in place are implemented through the online system. This method uses the Teach pendant command method.

When ordering by this method, all processes will have to be stopped during that time. For this reason, in most cases that time will have to be spent in vain. Also, if there is an error in the commands given, you will have to pause the process again to resolve it. The answer to all of this is that although there are people locally capable of producing cheap machines, they need a suitable control system. Another problem is the lack of such controls. In view of all these factors, local small scale manufacturer warrants are facing a very problematic situation.

1.3 PURPOSES

It is a time of increasing focus on automation. The major purpose of this study is to create a robot manipulator suitable for offline robot manipulator system that can be easily used for small scale factories. This should be designed to suit the needs of small-scale factories at an affordable price. Although the main target is small scale factories, this will be important for all other factories. Financial status can be controlled by minimizing start-up costs as well as maintenance costs. Under this major project is the creation of a low-cost offline platform and the creation of a robot manipulator suitable for use. The purpose of this study report is to design and build a robot manipulator suitable for the second purpose system. The main objectives here are to adapt the end effector so that I can modify it for other processes and use it easily and easily. This allows a limited amount of machinery to carry out all the processes required for an organization. This will save a lot of money. Here we hope to finally present the design and design for it. It also offers a prototype for testing. The prototype gives a complete idea of the project.

1.4 SIGNIFICANCE, SCOPE AND DEFINITIONS

The solution to this problem is to design a prototype of a robot manipulator with a simple changeable end effector. Here the end effector is designed according to the desired processes and the ideas for a control system that can be commanded are presented here. This is done by building the prototype into a functional state through a system that has been configured to some extent. This is done by avoiding the high cost and difficulty of controlling pre-existing projects. Most of the existing systems are just concepts and a prototype is presented here. This will give you an idea of the future of the project. All existing systems are online and are designed to be suitable for offline platforms as well.

1.5 THESIS OUTLINE

This report is based on a study of the design of a robot manipulator. Chapter 1: introduces the problem, describes the background, and gives a basic idea of what happened during the thesis. In Chapter 1:, the study information provided is provided by a literature review. Chapter 3: describes how the project was done, the steps to follow and the prototype. In addition, the results obtained from Chapter 4: and the conclusion obtained from Chapter 5:.

Chapter 2: Literature Review

2.1 HISTORICAL BACKGROUND

In the past, the word robot was limited to science fiction. But by the 20th century, it was no longer so. The word robot is defined based on the Czech word roboto. It means slave or labourers. In the early days of researching robots, designers such as Carl Capek raised objections to this through plays such as RUR. It is based on the threat posed to humans by robots. After the robot introduced by General Motors in 1958 to produce motorsport, it was no longer just a science fiction novel. After the 1961 UNIMATE assembly robot, robots began to become popular around the world. The purpose of robotics was to duplicate or enhance the role of humans in areas where humans could not function. [1]

Tactile sensing for robotic applications became a separate topic of study in the 1970s. During the next decade, research continued to grow, culminating in Harmon's publication of one of the first overview studies on tactile sensing 1984. [2] The first advanced robot grippers, such as the DLR ROTEX gripper, were developed in the 1980s. It has laser range finders, tactile arrays, force/torque sensors, an integrated actuator, and analogue and digital circuitry for serial communication, all neatly wrapped in one component [3].

Since Harmon's paper in 1984, there has been significant development in several areas. However, the challenges now are largely the same as they wera in the past. He predicted that the company would grow quickly. This has not been the problem, though. Lee emphasized this argument in 2000, stating that in structured surroundings, humans may get a long way without tactile information. As a result, he believes tactile sensing will be most beneficial in unstructured contexts with unknown object attributes and/or the environment. [2]

Lee and Nicholls 1999 provide an overview of tactile sensing in mechatronics up till 1998 in their review paper. The number of published papers has gradually increased since then, as evidenced by the development of novel tactile arrays fabricated in silicon methods, the evolution of control, and the integration of systems. Over time, the emphasis has shifted away from the development of new tactile sensing technologies and toward data processing. [5] Simultaneously, powerful theoretical models of contact configurations and grip dynamics have been created. However, there has been very little research into the use of such models in conjunction with touch sensors. [2]

2.2 ROBOT MANIPULATOR DESIGN AND TECHNOLOGY

A robotic arm is a part of mechanical object that performs functions comparable to those of a human arm. It is usually programmable. The robot arm is the sum of the mechanism or part of a robot manipulator. The manipulator's linkages are joined by joints. That joint allows for either rotational or linear movement [6].

Tanii [3] describe an intriguing robotic arm system. Microbat's Alpha II [4] is a five-axis articulate robotic arm with a choice of conventional and specialized gripper mechanisms. It's a low-cost robot device that's been intended to assist people. Improve productivity by automating low-level tasks in industrial operations management. that are dangerous or impossible to repeat accurately for lengthy periods of time for human workers A five-axis articulate robotic manipulator, the Rhino XR-3 [5], is also available. This robot is capable of manipulating objects. It features a tough open design that makes it simple to examine. Every subsequent work on this This robot was used as a significant reference for the project [9].

The method of designing and building a prototype for a 5 device is described by Islam et. [6]. A microcontroller interfaced to a computer controls a DOF robotic arm. This As an end effector, the system has a two-finger gripper Yamamoto et al. [7] used real mobile manipulator robots to test a control method. so that the manipulator is always positioned at the top, based on their manipulability settings that you prefer Krainin et al. [8] devised a method for creating a three-dimensional surface model of things handled by a robot. Move the robot in front of the depth camera. Hao et al. [9] describe the design and development of a six degree of freedom PC-based robotic arm (PCROBOARM) based on the PUMA model. The robotic arm is based on a model. Soares et al. describe a Rhino XR4 robot-based robotic workstation [14] [5] [15]. This is a local thing. The created user interface aids in the programming of the robot and the execution of various tests. Visually guided movements, kinematics trajectory following manipulation task, etc.

2.2.1 robot arm joints

If broken down into its component elements, a robotic arm is a combined mechanical structure with motors that perform one of two operations revolute (R) or prismatic (P) (*Figure 2-1*). The prismatic is used for linear motion between two links, and revolute joints can only rotate around their axis. All necessary configurations in a 3-dimensional workspace can be produced with just these two operations [16]. Workspace is the area in which the robotic arm operates, this depends on the application of the robot and mobility of the specific type. An End-effector is required for the manipulator to interface with material. The end-effector is often a tool at the end of the arm that performs a duty such as scooping up objects at location to location. [10]

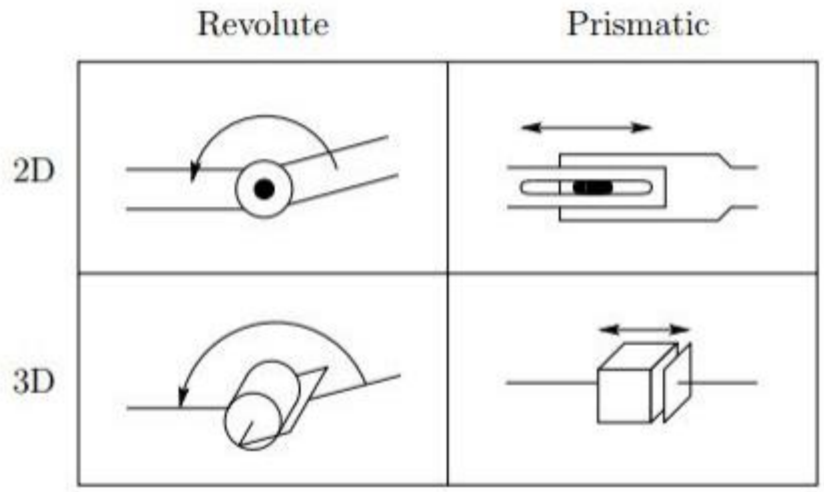

Figure 2-1: joint types

2.2.2 robot arm configurations

Robot arm was divided more types of based on configuration is important for the environment and purpose for which it is to be implemented. All types are show in (*Figure 2-2*) [10]

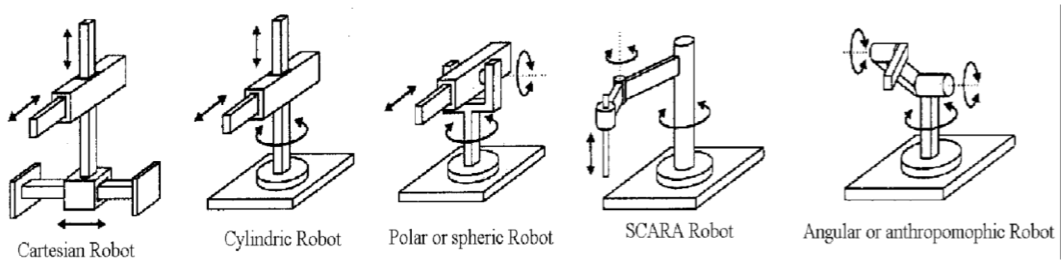

Figure 2-2 : robot configuration

2.2.3 Work envelops

Work envelop is the area in which the robotic arm operates, this depends on the application of the robot and mobility of the specific type. All workspaces are based on configuration of robot arm. (*Figure 2-3*) [10]

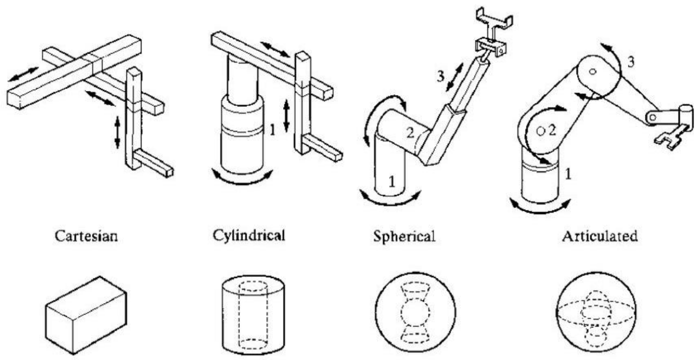

Figure 2-3 : work envelop

2.3 DEGREE-OF-FREEDOM

The degree of freedom refers to how manoeuvrable the manipulator is. If the arm is designed to reach all places in a workspace, it should have six degrees of freedom, three for positioning, and three for orientation. When a manipulator has more than 6 degrees of freedom, it gets more difficult to control, but it can reach further behind things. It would be impossible to reach all spots in a workspace with less DOF. To move the arm, it will need to modify the motors to reach a predetermined location. The Forward, Inverse, and Velocity Kinematics are the parameters required to do this. [10]

2.4 KINEMATICS OF ROBOT MANIPULATOR

The study of the movement of multi-degree of freedom kinematic chains that make up the structure of robotic systems is called robot kinematics [17]. The robot's connections are modelled as rigid bodies, and its joints are supposed to give pure rotation or translation, due to the emphasis on geometry. To plan and control movement and actuator forces and torques, robot kinematics explores the relationship between the size and connectivity of kinematic and the location, velocity, and acceleration of each link in the robotic system. Robot dynamics investigates the interaction between mass and inertia qualities, motion, and the forces and torques that go with it. [17]

Manjunath [11] performed kinematic modelling and analysis on a 5-axis stationary articulated robotic arm. It visualizes the kinematic model combining obstacle avoidance algorithms for the pick and place operation using the C++ language. De Xu et al. [12] looked examined the forward and inverse kinematics of a five-DOF robot. manipulator and proposed an analytical solution for the manipulator to follow a given set of instructions [17].

while preserving one axis in the end-effector frame in the same orientation Huang et al. [13] created a six-degree-of-freedom manipulator and conducted an inverse kinematics study. on it, using geometrical analysis to calculate the arm's trajectory. Iqbal et al. [14] and Iqbal et al. Deshpande et al. [15] constructed a six-degree-of-freedom robotic manipulator and studied its workspace. The robot's kinematics challenges were solved using the robotics toolbox in MATLAB. The forward kinematics of the manipulator are predicted using DH parameters, and the joint angle of the arm is determined using inverse kinematics. For overcoming the inverse kinematic problem of redundancy resolution for robotic arms, Artemia is et al. [16] developed a biomimetic approach. Zanchettin et al. [17] provided a study on how to use a robotic controller to exploit the kinematics of a human arm. The motion of the human arm is studied and synthesized in this experimental approach. For quotient kinematics machines, [18] propose synthesis theory and geometric analysis (QKMs).

2.5 CONTRALLING SYSTEM AND COMAND PLATFORM

A programmable hardware machine and its associated program are referred to as a control system. A robot's control system is thing of the most important systems. It is made up of sensors, controls, and knowledge bases, among other things, that allow the robot to do useful tasks. Robots are frequently classed as non-servo or servo depending on the sort of control method they utilize. Non-servo robots, often known as non-intelligent robots, were the first form of robot. Servo robots, the second type, are intelligent robots [25]. There are have number of two main types of control systems. First one is open loop and closed loop. This type systems are used by non-servo robots. In this system, there is no feedback mechanism. Closed-loop systems are used in servo robotics. [19] The feedback signals are supplied to the servo amplifier in a closed-loop system, which impacts the output of the system. (*Figure 2-4*) depicts an open-loop control system. The phrases input and output explain the cause and effect relationship in this simple system [8].

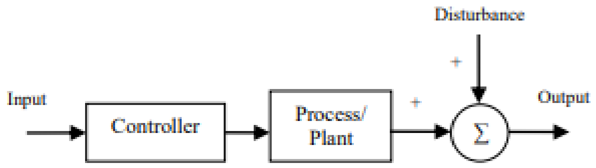

Figure 2-4: open loop control system

The desired set point that the controlled variable should achieve and remain is the input. The controller controls the process or plant, [19] which is one of the system's components. The system's output is the result of the process or plant after any disruptions have been applied. Because the open-loop arrangement does not account for any disturbances introduced into the system, any disturbances that occur become part of the output. Open-loop systems are incapable of detecting disruptions in real time. [19] An open-loop control system has the advantage of a simple and straightforward input-output relationship. The drawbacks are discovered. The inability to detect and compensate for system disturbances is one of the downsides [25]. Depending on the type and purpose of the system, these drawbacks may have negative repercussions.

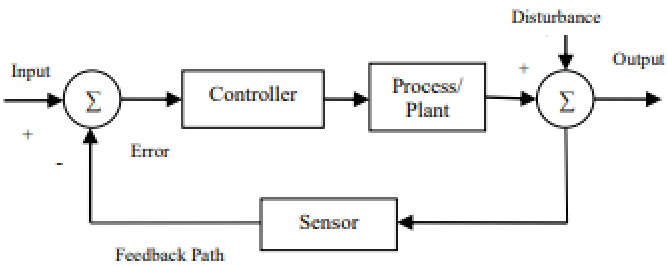

Figure 2-5: closed loop control system

The closed loop system tries to compensate for the drawbacks of the open-loop structure. A feedback line is added to a basic closed-loop system (*Figure 2-5*) to compensate for disruptions. The user sets the system's input or set point to the intended value for the manipulated variable to attain and maintain. [19] The input is connected to the output via the feedback path at the first summing junction. To discover the error, subtract the output value from the input value. When these numbers are compared, the process or plant is prompted to make any necessary adjustments [19].

2.5.1 Online and offline platform

1.1.1.1 Online platform

The robot is stopped, taken out of production, and put into programming or teaching mode using online programming methods. The articulated robot is then used to generate or modify programs. [20]

Teach pendant programming: The most used way for programming industrial robots is teach pendant programming method. Approximately the greatest number of industrial robots are programmed using teach pendants method. A suitable pendant method, which is a handheld device that plugs into the robot manipulator. The pendant's interface can then be used by programmers to construct or change application of programs [27].

Lead through robotic programming: Lead through robotic programming is a simple approach of manually guiding the robot arm through the application's waypoints. Hand guided programming is another name for this method.

2.1.1.1 Offline platform

Offline programming is using programming software and a simulated work environment to create robot programs on a computer. Offline robotic programming, unlike online robotic programming, does not necessitate the presence of the robot. [20]

offline software was used to change program. To completely test and debug programs, a 3D duplicate of the robot's work environment is built using simulation [27]. When a program is finished, it is transferred to the robot. Text-based or graphical-based offline programming software is available [20].

2.5.2 ROS

ROS is an open-source operating system for robots published under an open source. Its offers more than 2000 packages to its users. [20]

2.6 MOTORS

The application of force/torque in the form of a motor is required for this to even move. These motors come in a variety of designs and power sources, including servo motors, stepper motors, electric and hydraulic motors, pneumatic motors, and so on. This thesis will investigate and test direct current (DC) servo motors that work in pure rotation. A motor controller is frequently included with a servo motor to ensure that it receives the proper amount of current and voltage for precise and smooth movement. Motor controllers, often known as micro controllers, are devices that can store parameters and other settings. [10]

2.7 SUMMARY AND IMPLICATIONS

Robot Manipulator is one of the most widely used instrument in the manufacturing industry today. Most of the ones used in this way will be made for a special process. They will also require specialized control systems to manage [21]. Various strategies were found to explore the existing solutions to formulate a suitable methodology to provide a proper solution to the stakeholders facing this situation. Multi-purpose robots [22] and online commanding robots play a major role [21]. The Teach pendant method is used to implement this control system [23]. Using this method will take longer to issue commands. It is also problematic to have to stop all other processes when using this method. This can be pointed out as a major shortcoming found in existing systems. Creating a control system that can be modified individually will greatly reduce the cost of using one machine instead of the various machines that have to be used for different processes. But such systems are very expensive. The control process is also difficult. It should also be very convenient for the machine operator. A graphical user interface is a great alternative to the cumbersome methods available for this [24] [2] [26] [31].

Both labour and time can be saved if the graphical user interface can be used instead of encrypted control systems [25]. Thus, the lack of a proper methodology mostly affects local producers. Small businesses will need the right quality equipment to run them. This need is very prevalent in the work world today. When designing a multifunction robot, its conditions must be adapted to each of the processes it may refer to. It will be important to have a good understanding of arithmetic as well as scientific movements. This can be a problem if proper technology is not used. There has past research about that [28]. The main objective of the pick and place process is to create a robotic manipulator that is more cost effective. Here PLC is used as the microcontroller.

Servo motors for using as drives. This is made in 4 Degree Of freedom mode. Here the raw material is tested using software [26]. However, the lack of finishing on an industrial scale can be taken as a shortcoming here. But here the cost reduction has been done successfully [27]. DOF is another important part of a robotic machine. The number of independent modes of motion that can move to a dynamic system without violating any barrier is called the number of degrees of freedom. Statistical parameter estimates can be based on different amounts of information or data [8] [11]. The number of independent pieces of information that go into the evaluation of a parameter is called the free size. Ordinary robotic machines with six degrees of freedom perform orientation transformations and three rotations to the final impact.

The main purpose is to mount on an automated route for handling products in the automotive industry. [32] This includes special dynamics that allow the grasp of both circular and angular objects. Objects are grasped with three fingers, and the position of two fingers can be changed by a designed mechanism. Calculating the operating forces of the device is also incorporated into the technology of the robotic manipulator. The force required to grasp an object with the fingers under the considered frictional conditions is mainly calculated [28]. The results of the simulation calculations performed by the multiplier model of the robot have been shown to be well consistent with the results of the analytical calculations. In the numerical calculations, two different materials, AW-6802 aluminium alloy and S355 steel, [3] were considered. Both materials are acceptable with respect to the stress distribution of the energy structure. From an accuracy point of view, the plate structure made of aluminium alloy is more deformed than the plate structure made of steel. Productivity Steel is the most suitable material for production. The advantage here is the ability to handle even heavy loads. The disadvantage is that the speed is low [28].

The main purpose of this is to integrate the features of mechanical and robotics CAD software into one platform to facilitate the development process through a friendly interactive interface [14]. The platform provides important steps for developing a given robotic task defining a given task, learning CAD about the trajectory of the final task, testing the task maker’s ability to perform a task, mimicking motion, and avoiding trajectory collisions [20] [9]. Today, CAD prototype databases are widely used in industry such as AutoCAD, Ideas, Semantron, Katia and SolidWorks API for robot product design, modelling, and programming. An important advantage of moving away from the touch pendant method to the off-line method. Using a graphical user interface will also be very important [19].

Introducing servo motor selection technology for manoeuvre design. Similar output power cables are designed within the same load curve, giving another selection criterion. There is a temperature-based criterion for a continuous limit that estimates the constant selection temperature of a motor. It can be used to determine the appropriate motor and gear ratio [29]. All the above technical and theoretical considerations should be taken into consideration when building a Robot Manipulator.

A comparison of the different methods and solutions available to the problem can be filed in this way. Robot Manipulator will also require specialized control systems to manage [21]. Various strategies were found to explore the existing solutions to formulate a suitable methodology to provide a proper solution to the stakeholders facing this situation. Multi-purpose robots [22] and online commanding robots play a major role [21]. The Teach pendant method is used to implement this control system [23]. Using this method will take longer to issue commands. For an online control system, the instantaneous command that is introduced is captured by the machine. It will then be considered step by step and put into action. This takes a lot of time. Must also have specialized knowledge to control it. It will also require a machine that can trigger a variety of processes that are not specific to just one process.

Considering all these situations, a robot manipulator and a control system that can control the offline method can be introduced as the most suitable solution for this. In this way, the process can be continued by avoiding problematic situations in the existing Teach pendant type control system as well as in the uniform process [26]. This can greatly reduce the time and effort involved. This method will also provide relief to all parties to the problem. It will be very important for the work world. The offline control system can provide accurate data to the machine. With this, a multifunction machine can be set up to modify the process as needed and direct it to the various processes required [25]. Anyone can simply work with it by using a user-friendly interface.

Several control systems can be identified for robot manipulators. Electronic control systems, fluid control systems and air systems are those types. There is a tendency to use electric systems as well as air systems. Ventilation systems are becoming increasingly popular due to their high speed and power as well as relatively low cost and overall robustness. From the point of view of bio-robotics, pneumatic activators are most needed because they have many of the essential properties of living muscle at the mechanical level [30]. DOF is another important part of a robotic machine. The number of independent modes of motion that can move to a dynamic system without violating any barrier is called the number of degrees of freedom. Statistical parameter estimates can be based on different amounts of information or data. The number of independent pieces of information that go into the evaluation of a parameter is called the free size. Ordinary robotic machines with six degrees of freedom perform orientation transformations and three rotations to the final impact. The human hand, which is more efficient than the average robotic machine, has seven degrees of freedom, allowing humans to make more complex movements. In some applications, for example, due to indirect welding, narrow workspace, and complex movement, we may prefer to use seven degrees of freedom [31].

The main factors that determine a ma-insulator’s performance are servo actuators. The motion type of a servo actuator can be classified into two groups an incremental motion and a continuous motion. In an incremental motion, a servo actuator moves in a cyclic manner like start-move-stop. This kind of motion can be repeated occasionally as in an assembly machine or in a tele-operation. The main concern for these kinds of apply-cations is whether the servo actuator is capable of carry-ing out the transient dynamic load or not. In a continuous motion, a servo actuator moves in a constant speed or in a periodic speed for hours and days. Therefore, not only the transient capability but also the stable operation with a thermal balance is an important factor for selecting an actuator [32]. In summary, offline control is better than online teaching as a control system. It is also advisable to create a robot manipulator using an electronic solvent using a microcontroller. For this, the design should be done by selecting the solvent according to the function using kinetics and raw material testing.

Cost can be considered as the main factor in discussing the advantages and disadvantages of existing designs and products. The cost of most existing systems is very high. The main disadvantage of the teach pendant commanding method used in the online control system, which is prevalent, can be considered as time consuming. And the inability to change those systems is a major problem affecting local manufacturers [21]. There are also several systems that implement the offline method using a graphical user interface. The system as a whole will largely solve the above problems [24]. It describes an overall conclusion about the pros and cons, and explains each action separately above.

Considering the potential of existing solutions in reverse engineering, most existing systems are manufactured online. There are no solutions to the existing problems. Therefore, these systems certainly need to be redesigned to a greater extent than the existing ones. The offline control system can be introduced as the best method for this. When designing a robotic manipulator, a good scientific and technical design must be successful, taking into account the needs of the client as well as the needs of the system. This requires the use of an offline system and an advanced methodology. All its conditions must be determined by the challenges and needs that lie ahead.

Chapter 3: Methodology

This chapter describes the design adopted by this research to achieve the aims and objectives stated in section 1.3 of Chapter 1. Section 3.1 discusses the methodology used in the study, the stages by which the methodology was implemented, and the research design; section 3.1 details the participants in the study; section 3.2 lists all the instruments used in the study and justifies their use; section 3.3 outlines the procedure used and the timeline for completion of each stage of the study; section 3.4 discusses how the data will be analysed; finally, section 3.5 discusses the ethical considerations of the research and its problems and limitations.

3.1 METHODOLOGY AND RESEARCH DESIGN

3.1.1 Methodology

The initial stage of the study was to study the problem and analyse existing solutions. The final objective was to analyse the problems, design a solution and create a prototype based on the solution. The processes followed here can be listed as follows.

Problem analysis.

Here analysed how this issue has affected the society so far and which parties have been affected here. The main method used here is to collect and study information from old records. A literature review report was submitted within the first month.

Solution planning.

The next step is to develop a suitable solution for this. Several designs for this were made with various modifications. One concept plan was devised for the experiment.

Creating and testing a prototype.

A prototype was created using available resources to meet the current situation. Several different research activities were carried out using this. A program was developed to control the prototype.

Correcting mistakes and redesigning.

A new design was developed that solved the problems identified using the prototype. Its quality testing was done using software. A system for controlling this was also proposed as proposed.

Thus, the study was conducted. The final outputs of this study are a prototype and a final design.

3.1.2 Research Design

he main purpose of the study was to design a robot manipulator for an offline platform suitable for use in small-scale factories. In the first stage, the existing methods for this were studied and the key points needed for a more suitable solution were identified. The risk involved the initial cost as well as the minimum amount of resources required to use it. Here are the key factors that should be included in this solution:

1. It should be a low-cost robot manipulator.
2. Easy to make changes when needed.
3. Being a robot manipulator not limited to one process.
4. Suitable for an offline platform.

Considering these factors, it was necessary to set this up so that the process could be done by a robot manipulator. For this, it was decided to adjust the end effector so that it can be easily changed. It was decided to use lightweight material to make the motor needed for handling less expensive to use. Accordingly, attention was first paid to select the most suitable robot manipulator for this purpose.

3.1.2.1 Selection of the Manipulator type

Literature review has analysed that there are several ways to consider the configuration of a robot manipulator. Of these, the Articulated form is the one that can operate the most. For that reason, that method has been chosen. In (*Figure 3-1*) as show example for that configuration.

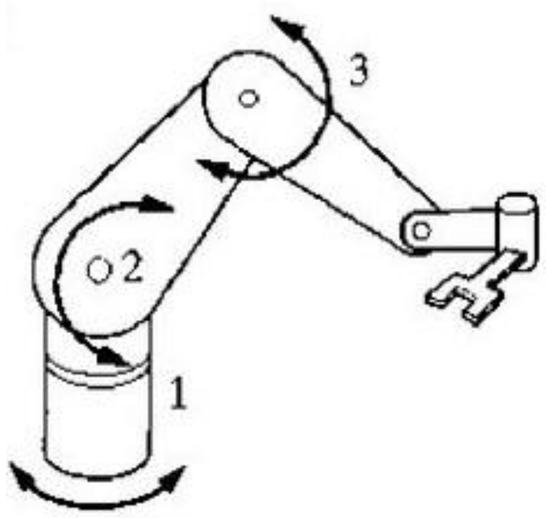

Figure 3-1 : Articulated robot

After considering all the factors, a 4DOF articulated robot manipulator was selected for the study. This can be termed as a TRRT robot manipulator. It consists of twisted joints and rotational joints (*Figure 3-2*:*Figure 3-3*).

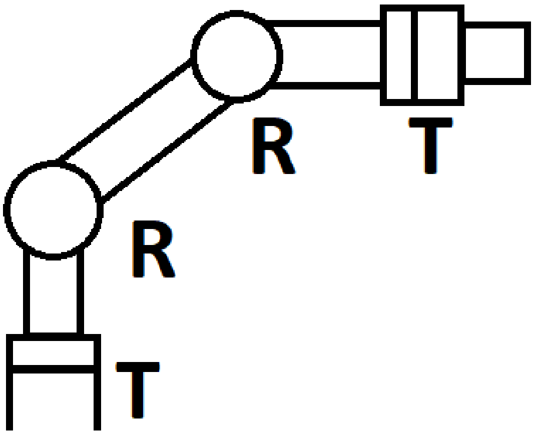

Figure 3-2 : joint configuration

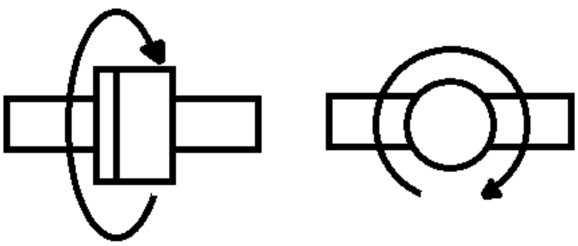

Figure 3-3 : motion of joint

3.1.2.2 Design and plan

The basic design of the manipulator is as shown in (*Figure 3-4*). More information about the design is attached in (Appendix A).

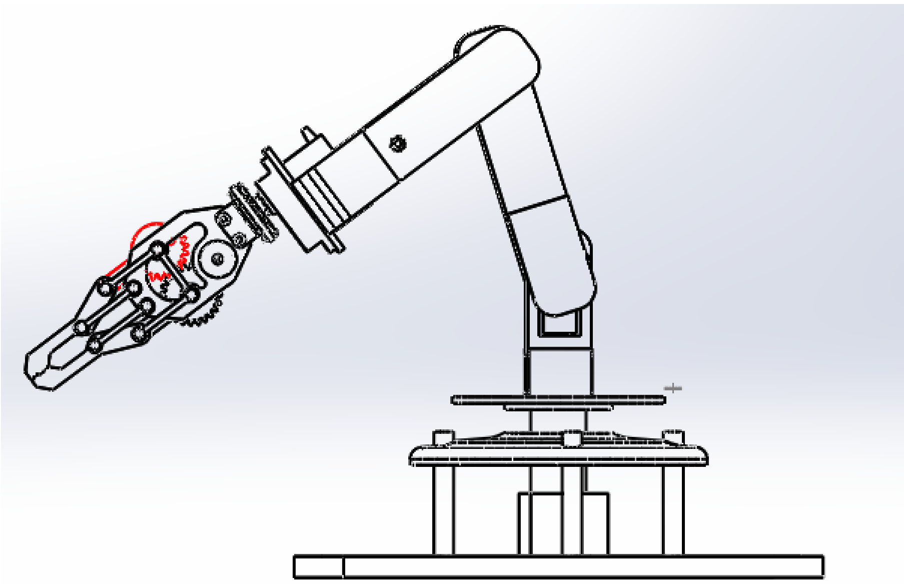

Figure 3-4 : basic design of manipulator

A 3D CAD design was developed based on this method. Solid work software was used for this. The 3D CAD design was drawn step by step according to a hand drawn plan. The 3D CAD design is shown in (*Figure 3-5*).

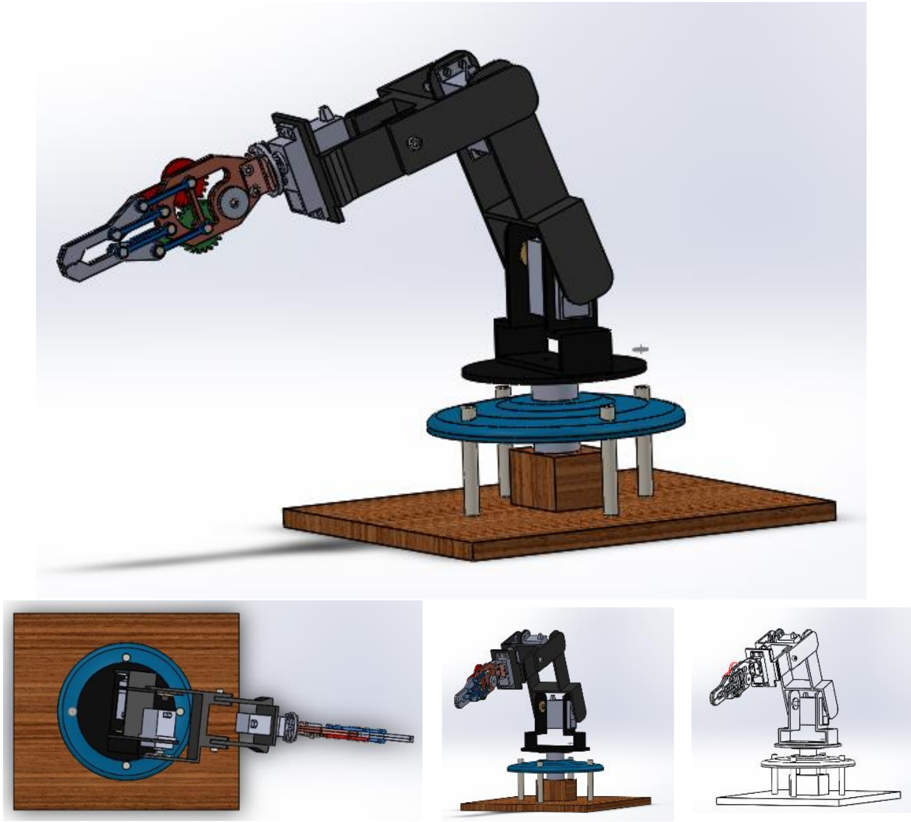

Figure 3-5 : 3D CAD design

Parts design for changeable end effector

It is designed to change the end effector so that one robot manipulator can perform several functions. It was designed in a way to easily change the end effector. Show in (*Figure 3-6*). In this, the existing device can be removed and replaced with another device when needed.

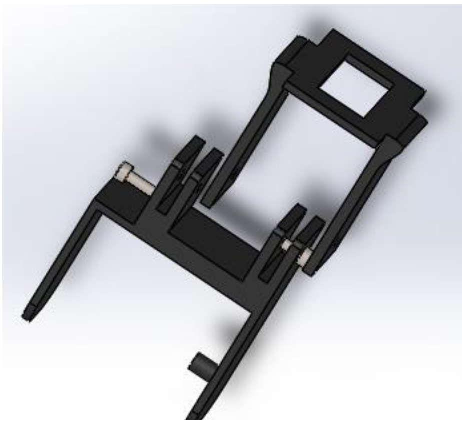

Figure 3-6 : changeable part of robot arm

3.1.2.3 Prototype

The prototype was designed according to a 3D design built using solid work. Various devices had to be used here. The basic components are set up using a 3D printer. Wood and metal were used to make the base section. Assembled using nut and bolt. An Arduino board and a DC servo motor were used to control this.

3D printing

A 3D printer was used to process the basic components. A 3-axis printer was used for this. Two types of infill structure were used in printing. Printed using PLA material.

Honeycomb infill structure. The most frequently employed infill pattern in 3D printing is honeycomb infill, also referred to as hexagonal infill. It offers tremendous component strength because of its hexagonal form. It also requires less wax to build the shape because bees intentionally or unintentionally create it (*Figure 3-7*).

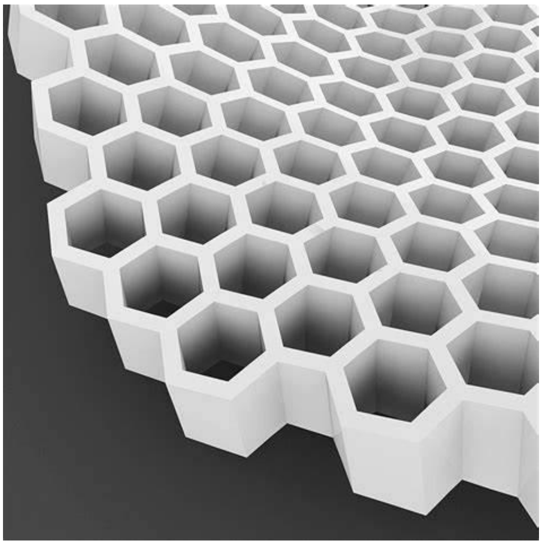

Figure 3-7 : honeycomb infill structure

Cubic infill structure. The structure of this infill pattern is a cube. One of its corners is also downward. Numerous air pockets are formed within the cubic pattern, acting as heat insulation. Its creation is not complicated, in contrast to the triangular and trihexagonal shapes (*Figure 3-8*).

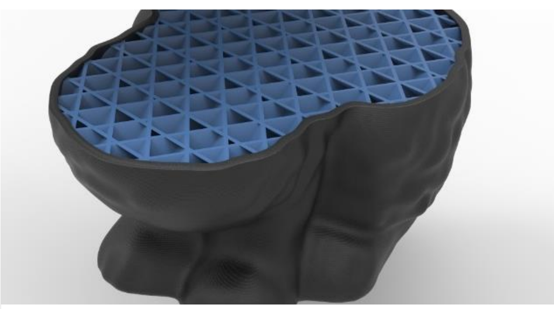

Figure 3-8 : cubic infill structure

The prototype was adapted using 3D printed parts and spare parts (*Figure 3-9*). Various techniques were used to reduce the force exerted on the axis and the force expelled on the friction. The use of bearing can be pointed out as an example of this. More information about the prototype is attached in (Appendix B : Appendix C).

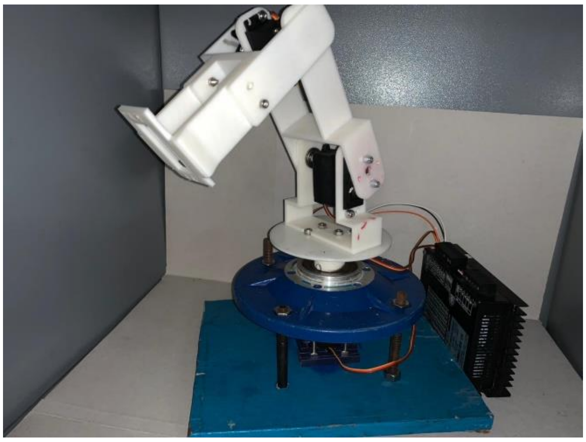

Figure 3-9 : robot manipulator prototype

3.1.2.4 Controlling platform

Creating a platform was not the main objective of this project. However, based on giving some idea about it, the focus was on developing a suitable platform to run the robot manipulator. The V-REP software was first tested for this purpose (*Figure 3-10*).

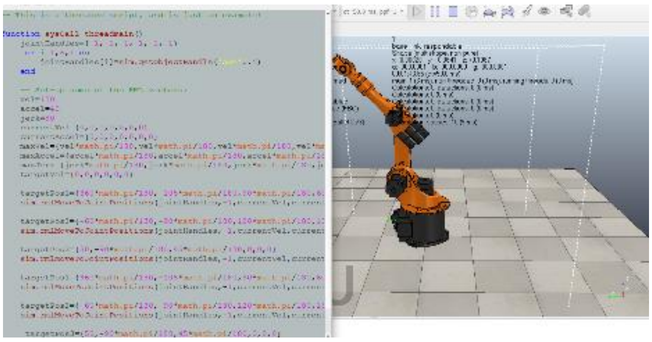

Figure 3-10 : V-REP testing

But it was difficult to import the URDF while doing so. It was decided to change the. Because software not a fully opensource software. The ROS software was then identified. It was a full opensource software based on Ubuntu / Linux. It is designed to distribute data to a microcontroller and control the robot manipulator (*Figure 3-11*).

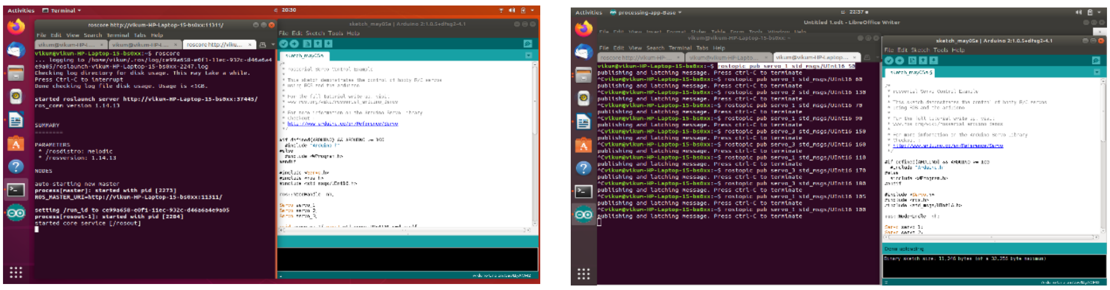

Figure 3-11 : ROS interface

The CAD drawing created using Solidwork was converted to a URDF. It was then input into the moveit software. After these basic steps, the prototype was controlled by sending data to the Arduino board using Rviz (*Figure 3-12*). Relevant coding and further details are attached in (Appendix D).

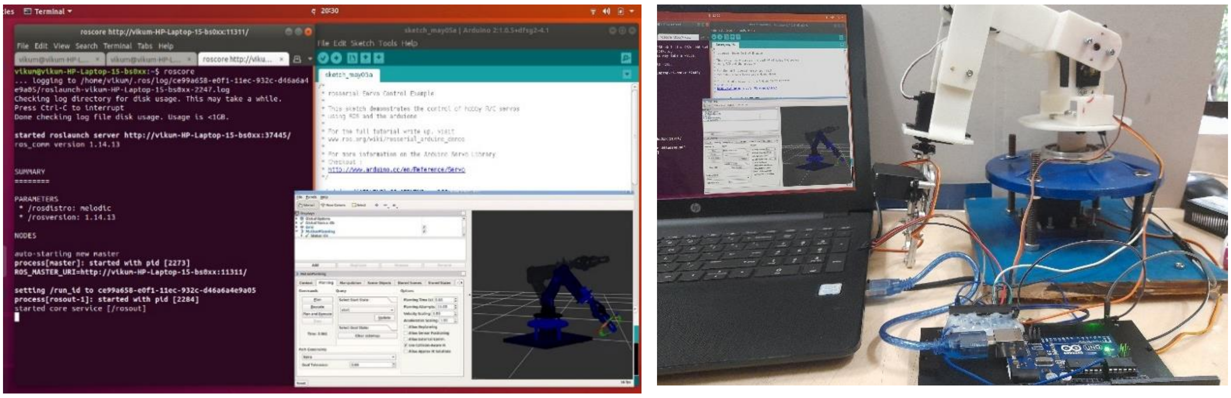

Figure 3-12 : controlling prototype with ROS and moveit

3.1.2.5 Redesigned robot manipulator

The design was redesigned without bugs in prototype. This was designed to avoid errors and to be used in the industry. Calculations were also made to select the motor to be used for this purpose (*Figure 3-13*). More information about the design is attached in (Appendix E).

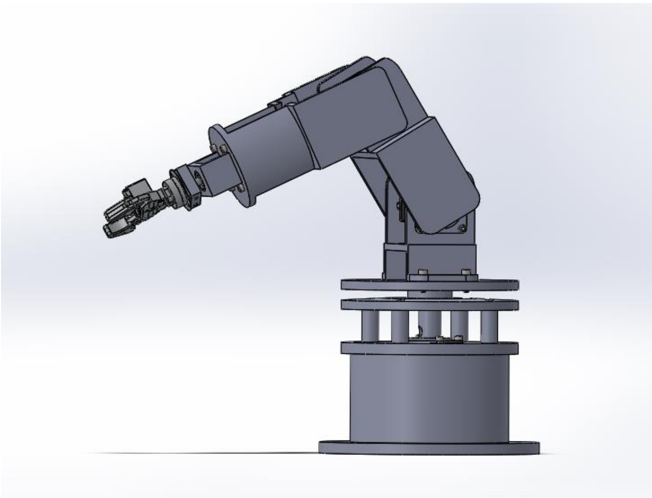

Figure 3-13 : new manipulator design

Changeable end effector parts of new design

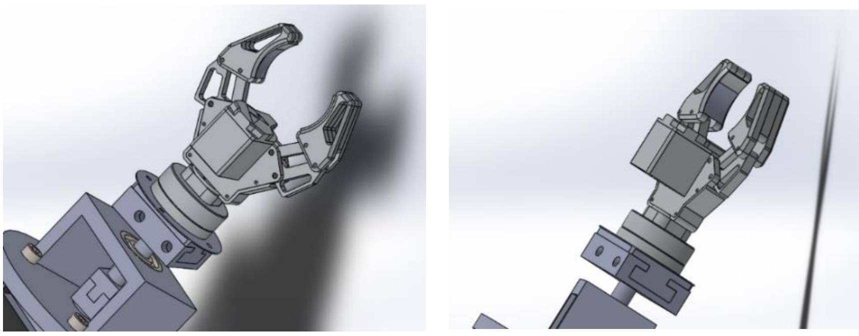

Figure 3-14 : Changeable end effector parts of new design

3.1.2.6 Motor selection

Calculations were made to select a motor that could handle an additional 20N of power. Following these calculations. It was recommended that the following motors be used for this purpose.

For J1 : ATO130ST-M10010 (1KW | 4/10Nm | 2500 rpm)
For J2 : ATO130ST-M10010 (1KW | 4/10Nm | 2500 rpm)
For J3 : ATO110SY-M05030 (1.5KW | 5/15Nm | 3000 rpm)
Base point : ATO130SY-M10010 (1KW | 10/25Nm | 1000 rpm)

More calculation about the motor selection is attached in (Appendix F).

3.1.2.7 PLC and HMI program for controlling new design robot arm

PLC program was created using Haiwell PLC software for central servo motors of robot arm. And Hiwell was used create an HMI panel for control that PLC program (*Figure 3-16Figure 3-15*). More details in (Appendix G)

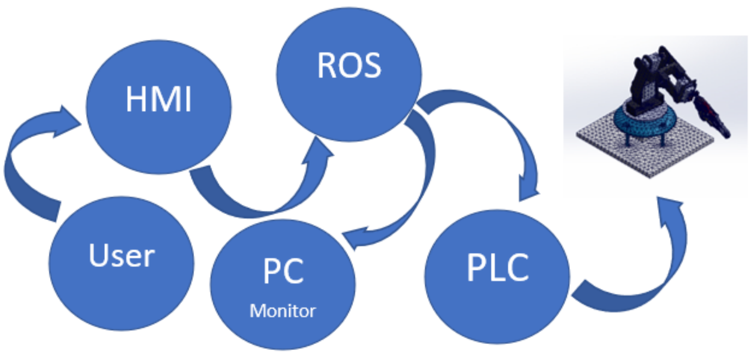

Figure 3-15 : HMI panel and PLC program

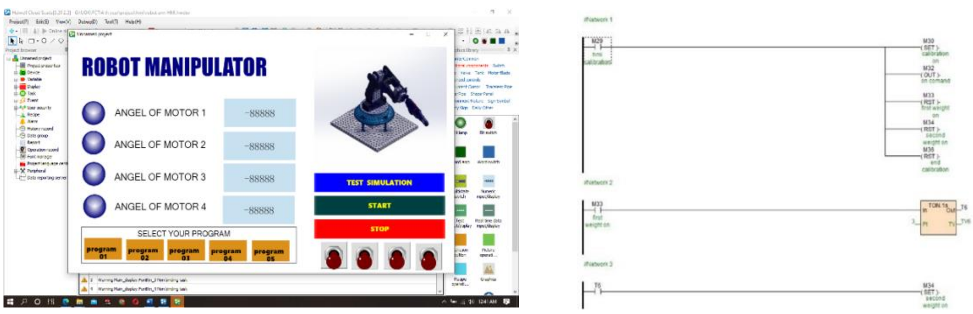

Figure 3-16 : controlling system

3.2 INSTRUMENTS

The main methodology used for the study was to study old records. This prepares a separate report. Old reports and web articles have been used for this. This is done and several software and accessories are used during the season.

SOLIDWORKS

SolidWorks software is a solid modelling computer-aided design. This software was used to design and analysed 3D modal. And used this software to convert 3D modal to URDF. URDF was used import 3D modal to ROS platform (*Figure 3-17*).

Figure 3-17 : logo of solid work

ROS

ROS is a robot controlling platform. Ros was used send angel to Arduino in this project (*Figure 3-18*).

Figure 3-18 : logo of ROS

3D printer

Figure 3-19 : 3D printer

All protype parts was printed using 3D printer. It is 3 axis printer (*Figure 3-19*).

Arduino UNO

Figure 3-20 : Arduino UNO Bord

The Arduino Uno is an open-source microcontroller created by Arduino. That is based on the Microchip. ATmega328P microprocessor of this. A variety of expansion boards and other circuits can be connected with the board's sets of digital and analogue input and output pins. Arduino board was used to controlled servo motors of prototype (*Figure 3-20*).

DC Servo motors

Figure 3-21 : MG 945 servo

MG 945 servo motors are used this prototype. This is a DC servo motor (*Figure 3-21*). Rotational angel is 180^{0}.1)a)Appendix H)

Bearings

Figure 3-22 : bearing

Main Purpose of a used ball bearing is to reduce rotational friction and support radial and axial loads withing two axis of robot arm (*Figure 3-22*) .

3.3 PROCEDURE AND TIMELINE

The study was conducted under three main objectives, investigate about problem, planning and design, fabricate a prototype. In the first objective, studied robotics, kinematics, dynamic theories for robot arm, software, and equipment studies were performed. In the second objective, manipulator kinematic and planning, material and equipment testing, and CAD designing processes were performed. The prototype was fabricated and finalized during the final objective. (*Figure 3-23*) shows how the work is divided on time.

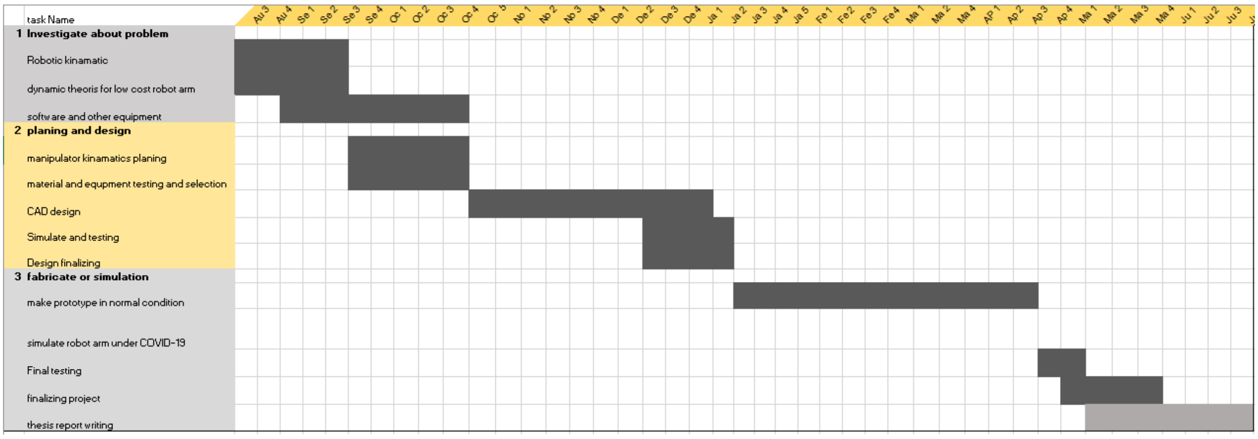

Figure 3-23 : Gant chart of project

3.4 ANALYSIS

The prototype was tested several times using solid work simulation (*Figure 3-24*).

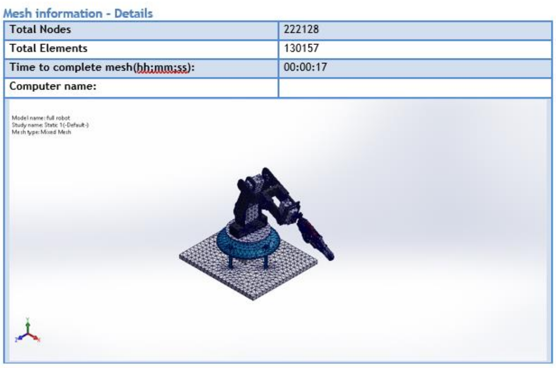

Figure 3-24 : solid work simulation work

Data were collected using different weights for the prototype designed according to the first design. These data were used for the first analysis. The focus was on how the robot manipulator works according to the weight applied and the changes that occur in those situations. The impact on the robot manipulator components and the changes to be made to the motors were identified. Changes in the assembled parts were also identified. The material used and the infill ratio were also taken into consideration. It was concluded that it would be appropriate to further reduce the weight of the upper parts of the robot manipulator. Several instances in which this analysis process is performed are shown in (*Figure 3-25*). .

After analysing the data obtained using the prototype, several problems were identified. Later a new plan was created to solve those problems. The primary focus was on the quantity used and the raw material used. The way the parts are connected also drew attention. The design was then tested using solid work at various weights. The data collected were also analysed. Several such instances are shown in (*Figure 3-26*).

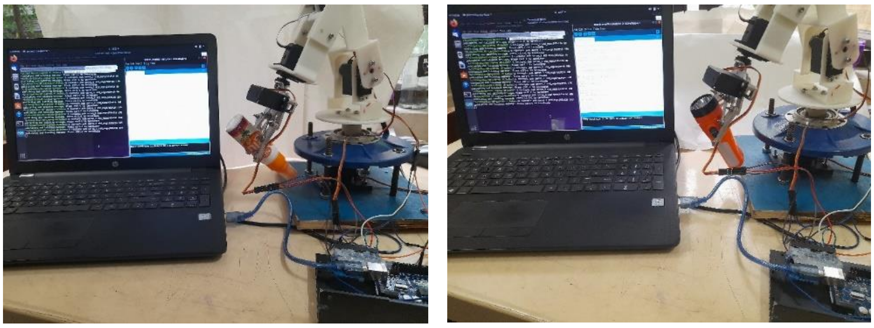

Figure 3-25 : prototype testing

The analysis process was carried out using the above two main methods. The main points analysed by this are as follows (*Figure 3-26*).

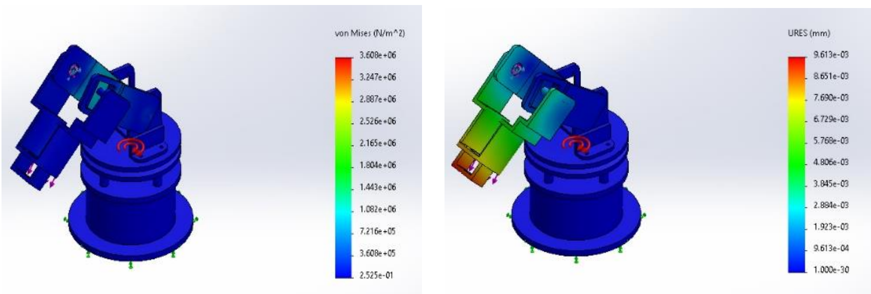

Figure 3-26 : solid work simulation and analyse part

Selection of raw material

Instead of assembling all the parts of the robot manipulator from the same material, the upper parts should be made of lighter strength less material and the lower parts energy from more low-cost material. The reason for doing this is to be able to use a smaller motor to control the lighter parts. In addition, the cost can be reduced by processing the lower parts with other raw materials.

Motor selection

Here it was analysed that it is appropriate to choose servo motor instead of conventional induction motors. This is because servo motors can be controlled to a certain degree. This was also the reason for using servo motors instead of gear motors when designing the prototype.

Using bearing for the base.

The upper bouts featured two cutaways, for easier access to the higher frets. By applying that power through a bearing, the used motor can be used with less power.

Use thread instead of nut and bolt.

The nut and bolt may loosen due to the impact of the motor vibration. This method can be used to prevent it.

Use of honeycomb and cubic structure for 3D printing infill structure.

The reason for using honeycomb and cubic structure for this is its robustness and low infill percentage.

Using ROS to replace V-REP software.

ROS was used for the final design. It was decided to use ROS as V-REP is not a completely opensource software.

Proposing PLC and HMI owned by Haiwell.

This was since most of the other devices had to be purchased with programming software. Another reason for this is that the software is very easy to work with. In this way, these thorns were analysed through test sessions and study sessions.

3.5 ETHICS AND LIMITATIONS

In discussing ethics in this regard, a key point to note was identified. When installing a robot manipulator in a factory, care should be taken about the impact it will have on the people who work there. As a result, it can sometimes be a threat to their job. Or it could be a security breach. These things need to be constantly considered. Therefore, solutions to these problems must be found at the planning stage. This study will show the maximum limitation of the robot manipulator as a limitation of lifting weight and the maximum work environment it can reach. The maximum weight is 2kg and it can be customized according to the design. The accessible work environment can be increased in the same way. Also, the lack of accessories and the high cost of processing this can be pointed out as a limitation. Lack of resources for studying ROS software is also a problem here. But since my main goal was to create a robot manipulator, it was not that much of a problem.

Chapter 4: Results and Discussion

Robot manipulator motion and motor angel data taken using inverse kinematics to detect the position of object. Input and output positions of robot manipulator are show in (*table 4-1*).

No	Inputs			Outputs						
	Position Cm			Position Cm			Motor angel ^{0}			
	x	y	z	x	y	z	Q_1	Q_2	Q_3	Q_4
1	10	5	0	9.8	4.9	0.9	0	75.2	50.6	0
2	10	6	5	10.1	5.7	5.1	0	76.8	52.9	0
3	15	8	6	15.5	8.3	6.2	51.3	101.1	62.4	15.6
4	14	9	0	13.9	9.6	9.1	45.2	98.5	59.6	10.6
5	12	3	8	11.1	3.1	2.9	35.3	81.2	55.6	11.8

table 4-1 : angel and position of robot manipulator

The final results were obtained by activating the robot manipulator on several occasions using two coordinates belonging to several locations. Those data are shown in (*table 4-2*).

No	Input position			Output position		
1.1	10	6	5	9	6.2	4.2
1.2	10	6	5	10.1	5.7	5.1
1.3	10	6	5	10.6	5.7	5.3
1.4	10	6	5	10.5	6.1	4.8
2.1	12	3	8	12.5	3.1	7.5
2.2	12	3	8	11.9	3.6	8.3
2.3	12	3	8	12.3	3.2	8.1
2.4	12	3	8	11.1	3.1	2.9

table 4-2 : position result

The data obtained from the test sessions are included in (*table 4-3*) to obtain the weights that can be lifted by the prototype.

Test No	Value N	Ability
01	0.1	Yes
02	0.3	Yes
03	0.4	Yes
04	1	Yes
05	2	Yes
06	2.5	Yes
07	2.6	Yes
08	2.9	No

table 4-3 : ability lifting face value of prototype

After all these test sessions, it was concluded that the maximum force that could be applied to the lift by the prototype was 2.8 N. The distance that can be reached is shown below.

X = (-25.+36) Y = (-36.+36) Z = (0.+20)

The basic results obtained from solidwork for a redesigned robot manipulator are tabulated as follows (*table 4-4*).

REACTION FORCES

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	-0.432617	0.834085	-0.933213	1.32429

FREE BODY FORCES

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	-0.317755	0.0004009	-0.231791	0.393313

table 4-4 : reaction face and free body face of robot arm

Considering all these results, the robot manipulator can be redesigned to factory level and can withstand an additional 20N of power.

The following outputs were obtained from the study.

- ROS base robot controlling platform.
- PLC and HMI base controlling system.
- Prototype of robot manipulator.
- CAD design of robot manipulator for use industry level.

The study began with the design of a robot manipulator for an offline platform, suitable for small - scale factories. Based on this, an analysis of basic technical knowledge was carried out. In the process that followed, a suitable robot manipulator was first developed as a concept design. It was then created using solidwork. Accordingly, a prototype was created using various methods.

An offline platform was roughly set up using ROS software to control that prototype. This platform and prototype were subjected to various tests. Tests were performed using different weights to identify problems. It concluded the raw material and technical tools to be used. The prototype could only control 2.8 N of extra power.

Taking all this into consideration, a new design was developed using solidwork. Later it was also used by the software for testing in various ways. These processes eventually presented a complete design for a robot manipulator that could be used at the factory level. It was designed to withstand an additional force of 20 N.

The platform built to implement the prototype was built based on ROS and Moveit. An Arduino board was used to power its servo motors. A PLC and HMI were proposed to run the reconfigured robot manipulator. A suitable program was presented for that too. A program using the C language is also presented to calculate the number of degrees to be given to each of these motors. The end effector of this robot manipulator is also designed to be easily modified. This allows to set up a single robot manipulator to perform multiple tasks. This is designed to be modified to suit. It was designed in such a way that this part can be removed, and another part can be attached very easily. After this change, you will need to make some changes in the relevant program. It was set up in such a way that it could simply be commanded by the HMI. The end result can be easily modified at any time using a single robot manipulator. This can save more cost not only for small scale factories but also for any other factories.

Open-source software such as ROS has been used to carry out the control process here so that anyone can make changes as they see fit without being bound by any legal framework. You can save time and effort by programming offline, away from the teach pendent method. You can also pre-plan and store any program you need for the future. The PLC and HMI program that comes with this are just a few basic steps. That is, to be able to activate motors. Argument can be constructed appropriately in use. At the end of all these processes, this study presents a robot manipulator and a controlling platform suitable for any factory. All of these have been successfully presented in such a way that anyone can set them up on their own, overcoming all existing solutions. This system can be set up for a factory at a very low cost.

Chapter 5: Conclusion

At the end of the study, an appropriate solution to the problem was developed. A control process was presented using ROS and several other software. For the whole process, what was available, cheap or free, was used at all times. The end result is a prototype and a solidwork design. In addition, an offline platform developed to some extent has been presented as a result of the study. The main purpose of this study was to design a robot manipulator suitable for an offline platform, and the platform's were another major objective. But with this comes an outline for an offline platform. It also has a built-in PLC program.

A robot manipulator is a very important part of the now world. This study presents a robot manipulator suitable for small scale factories. This is designed to be suitable for use in factories of any quality. A learning methodology is needed to further the study. Most of the software used for this has been studied individually and used with advanced knowledge. This study would have been even more successful if there had been a workshop to learn more about software like ROS.

The literature review was very important for this study. By doing so, the problems in the old presentations could be heard. Going through those identities gave the opportunity to give a better output. This offers a cost-effective method that is easy to use for small-scale factories. This was done in such a way that it could make any change to their liking. Then they can use one manipulator with changes instead of many robot manipulators that they have to buy for small actions. It is also easy to modify the programs for any changes easily using the available hardware and the study is provided in a way that does not fall under any legal framework.

Under the prevailing global crisis and epidemic, it was very difficult to find the resources needed for the study. As a result, there was no opportunity to implement any plans. However, in the face of all challenges, the study was completed to the maximum extent possible.

5.1 RECOMMENDATION

This study presents a robot manipulator that can be easily and cheaply installed for factories. It is advisable to use lightweight, strong materials whenever possible. It is also advisable to use motors with brakes when using motors. Or the manipulator may be damaged when there is no power on the motor. It is also advisable to use low-cost accessories at all times to reduce costs.

The maximum usable weight is recommended according to the calculations presented here. If the sun is expected to handle a heavier load, it should be calculated and used accordingly.

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[34] E. M. Magazine, “A motor selection technique for designing a manipulator.,” 2002.

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Appendices

Appendix A

design and plan for prototype

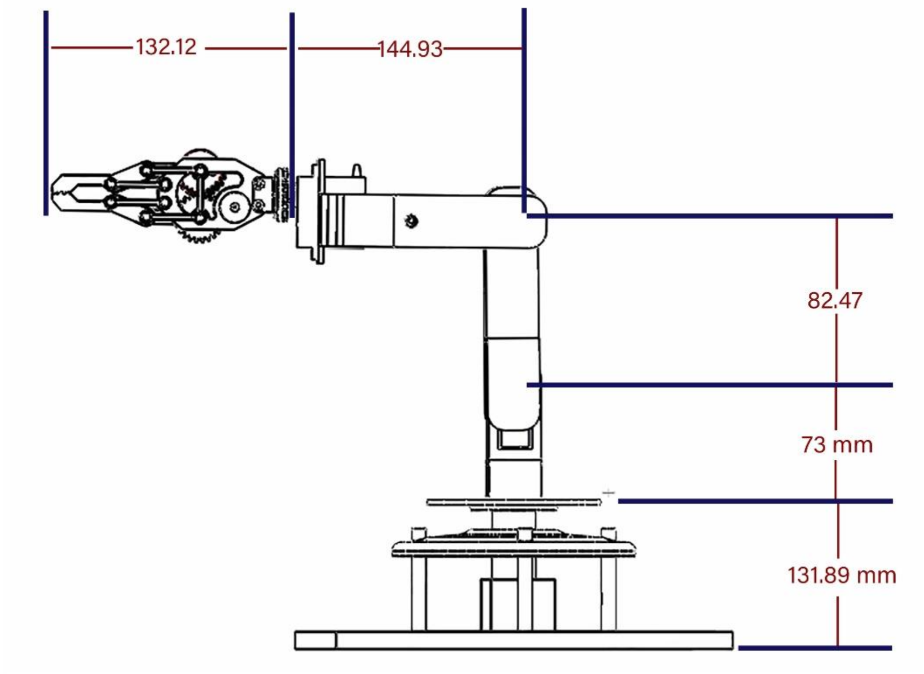


Figure A-0-1: basic dimension of prototype

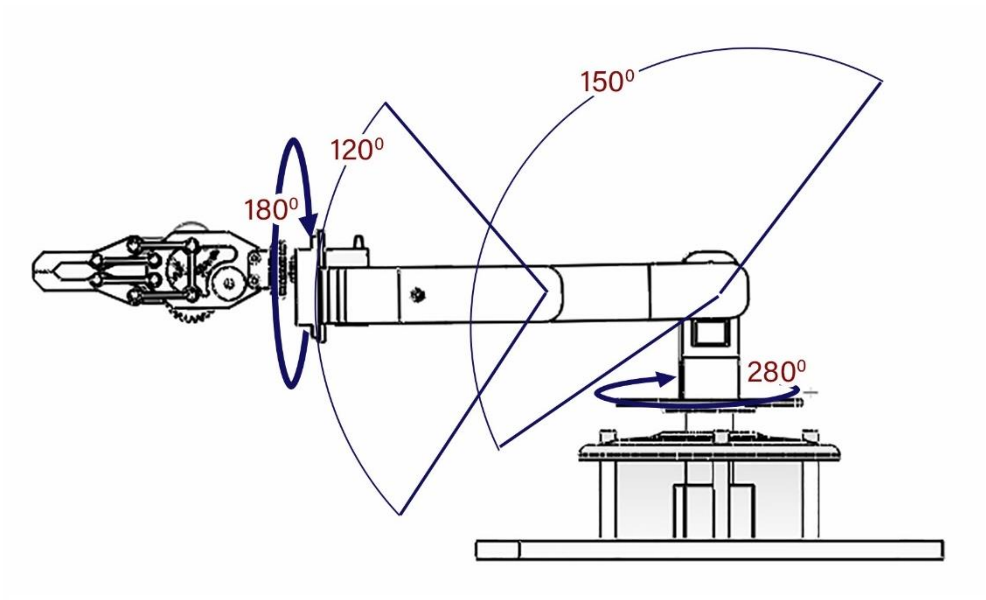


Figure A-0-2 : rotational limitation

Parts of the robot arm

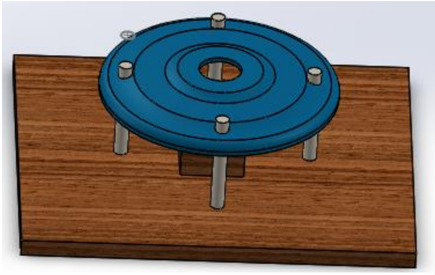
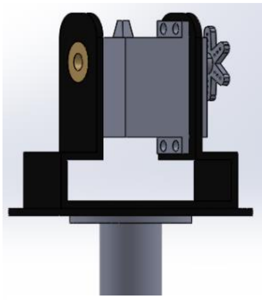
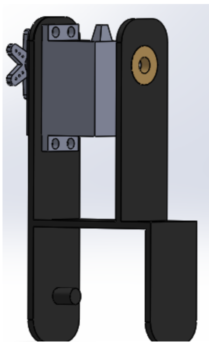
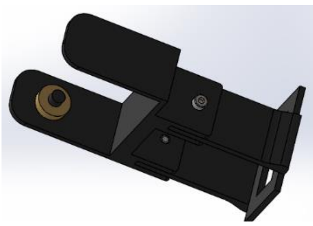
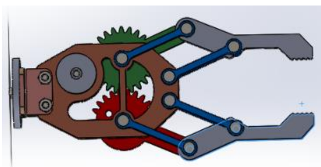
Name of part	3D model	description
Base of robot	 *Figure A-0-3 : base of prototype*	This is base part of robot arm. Base part was created using wood and metal.
Link 1	 *Figure A-0-4 : link 1*	This is first link of robot arm. This arm work in as twisting joint.
Link 2	 *Figure A-0-5 : link 2*	This is second link of robot arm. This part work in as rotational joint.
Link 3	 *Figure A-0-6 : link 3*	This is third link of robot arm. This part work in as rotational joint.
Gripper	 *Figure A-0-7 : gripper*	This is gripper for pick and please task.

table A-0-1 : parts of prototype

Workspace of the Manipulator

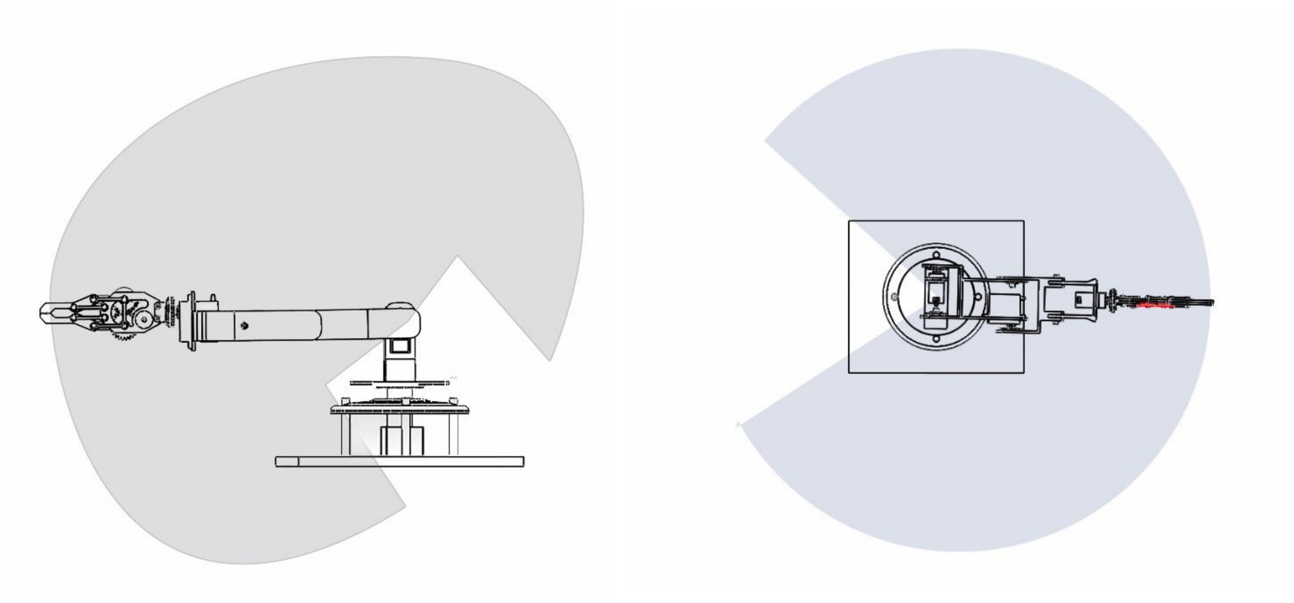


Figure A-0-8 : workspace of prototype

Appendix B

details of prototype

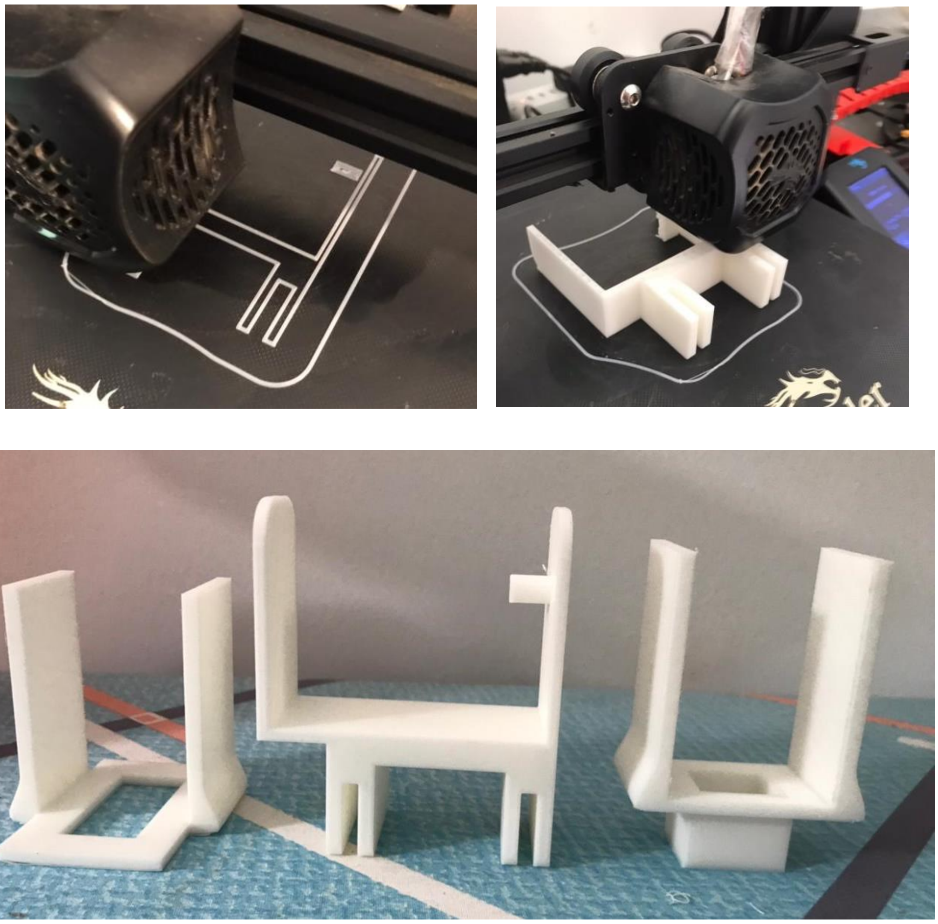


Figure B-1 3D printing parts

Base part of robot arm

Attached a metal plate to a piece of wood and made the base section. An 8mm allene nut was used to connect the wooden part and the metal plat. Here a boll bearing was used to connect the remaining parts. The reason for doing so was that the entire upper body could be easily activated by carrying the weight. Show in figure 3-17.

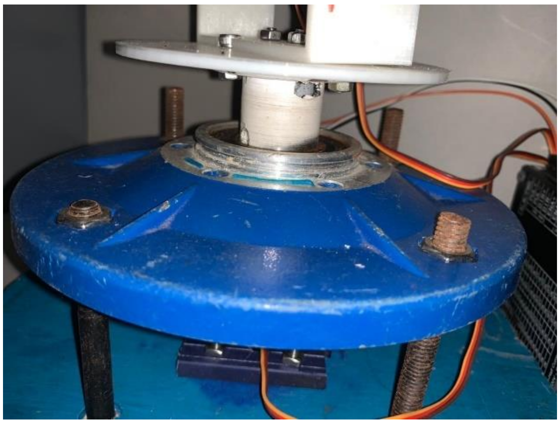


Figure B-2 : base part of prototype

Link part of the robot arm

There have three parts. All parts are assembled with allene nut and bolt. A boll bearing was used each time the links were connected. This allows the parts to move easily. Stock expiration can also be avoided. Show in figure 3-18.

Figure B-3 : bearing used

Gripper of robot arm

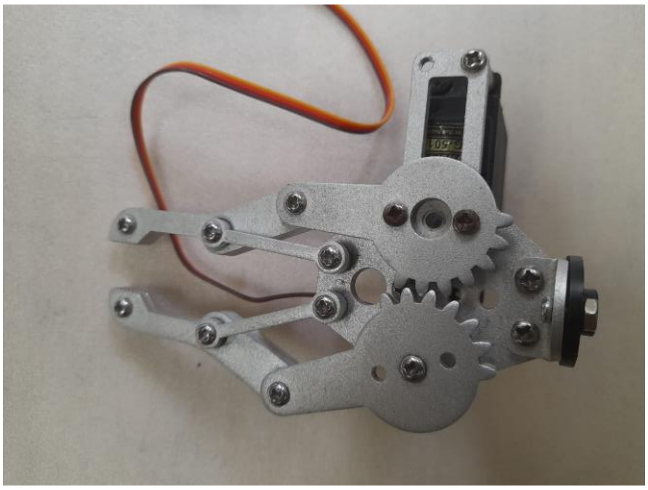


Figure B-4:gripper

Assembled robot arm prototype

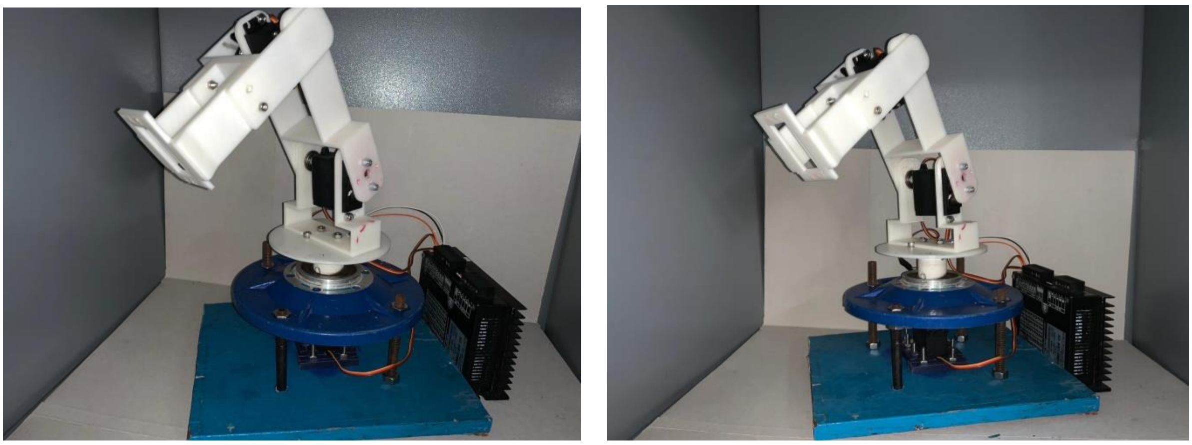


Figure B-5:prototype of robot manipulator

Appendix C

Circuit diagram of prototype

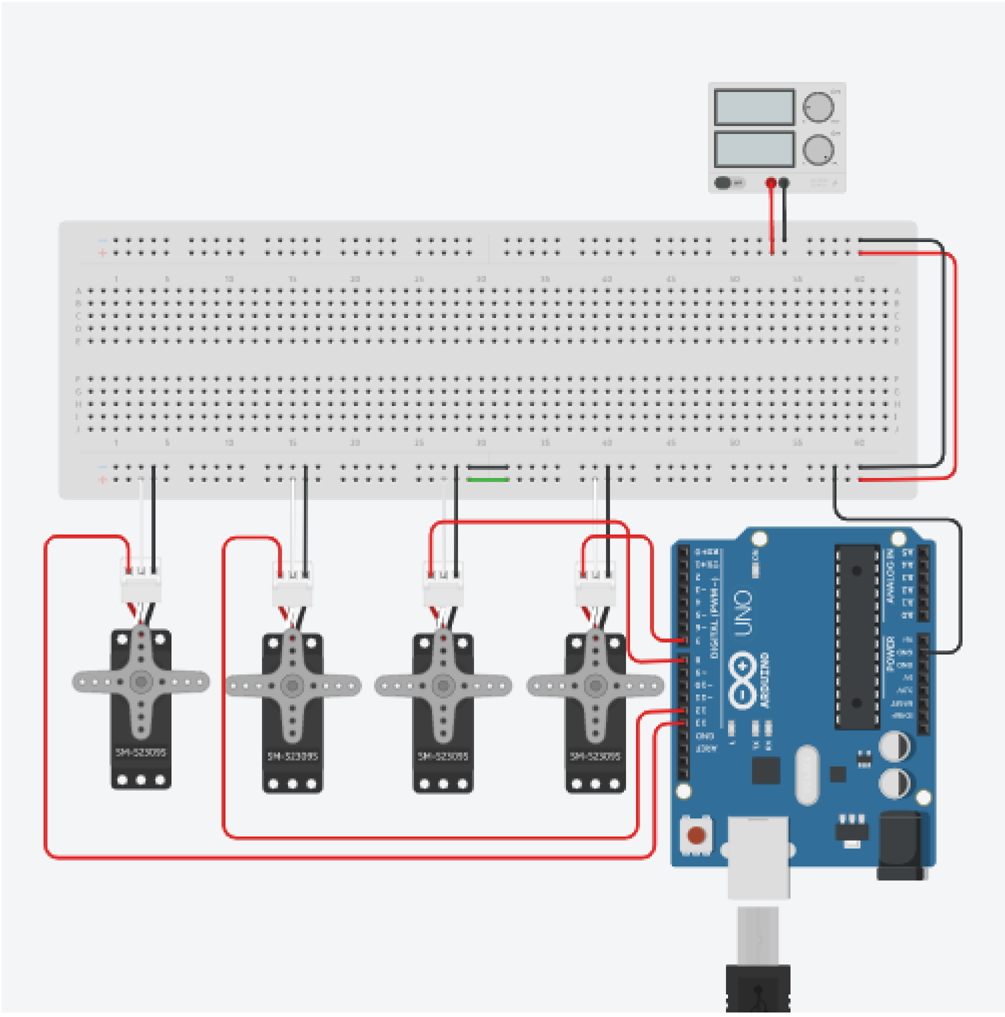


figure C-0-2 : circuit diagram of prototype

Appendix D

Controlling platform

Arduino program of prototype

```
#if defined(ARDUINO) && ARDUINO >= 100
#include "Arduino.h"
#else
#include <WProgram.h>
#endif

#include <Servo.h>
#include <ros.h>
#include <std_msgs/UInt16.h>

ros::NodeHandle  nh;

Servo servo_1;
Servo servo_2;
Servo servo_3;
Servo servo_4;
Servo servo_5;

void servo_cb_1( const std_msgs::UInt16& cmd_msg){
  servo_1.write(cmd_msg.data); //set servo angle, should be from 0-180
  digitalWrite(13, HIGH-digitalRead(13));  //toggle led
}

void servo_cb_2( const std_msgs::UInt16& cmd_msg){
  servo_2.write(cmd_msg.data); //set servo angle, should be from 0-180
  digitalWrite(12, HIGH-digitalRead(12));  //toggle led
}

void servo_cb_3( const std_msgs::UInt16& cmd_msg){
  servo_3.write(cmd_msg.data); //set servo angle, should be from 0-180
  digitalWrite(8, HIGH-digitalRead(8));  //toggle led
}

void servo_cb_4( const std_msgs::UInt16& cmd_msg){
  servo_4.write(cmd_msg.data); //set servo angle, should be from 0-180
```

```
  digitalWrite(7, HIGH-digitalRead(7));  //toggle led
}

void servo_cb_3( const std_msgs::UInt16& cmd_msg){
  servo_3.write(cmd_msg.data); //set servo angle, should be from 0-180
  digitalWrite(4, HIGH-digitalRead(4));  //toggle led
}

ros::Subscriber<std_msgs::UInt16> sub_1("servo_1", servo_cb_1);
ros::Subscriber<std_msgs::UInt16> sub_2("servo_2", servo_cb_2);
ros::Subscriber<std_msgs::UInt16> sub_3("servo_3", servo_cb_3);
ros::Subscriber<std_msgs::UInt16> sub_4("servo_4", servo_cb_4);
ros::Subscriber<std_msgs::UInt16> sub_5("servo_5", servo_cb_5);

void setup(){
  pinMode(13, OUTPUT);
  pinMode(12, OUTPUT);
  pinMode(8, OUTPUT);
  pinMode(7, OUTPUT);
  pinMode(8, OUTPUT);



  nh.initNode();
  nh.subscribe(sub_1);
  nh.subscribe(sub_2);
  nh.subscribe(sub_3);
  nh.subscribe(sub_4);
  nh.subscribe(sub_5);

  servo_1.attach(9); //attach it to pin 9
  servo_2.attach(10); //attach it to pin 9
  servo_3.attach(11); //attach it to pin 9
  servo_3.attach(5); //attach it to pin 9
  servo_3.attach(6); //attach it to pin 9
}

void loop(){
  nh.spinOnce();
  delay(1);
}
```

C# code of invers kinematic calculation.

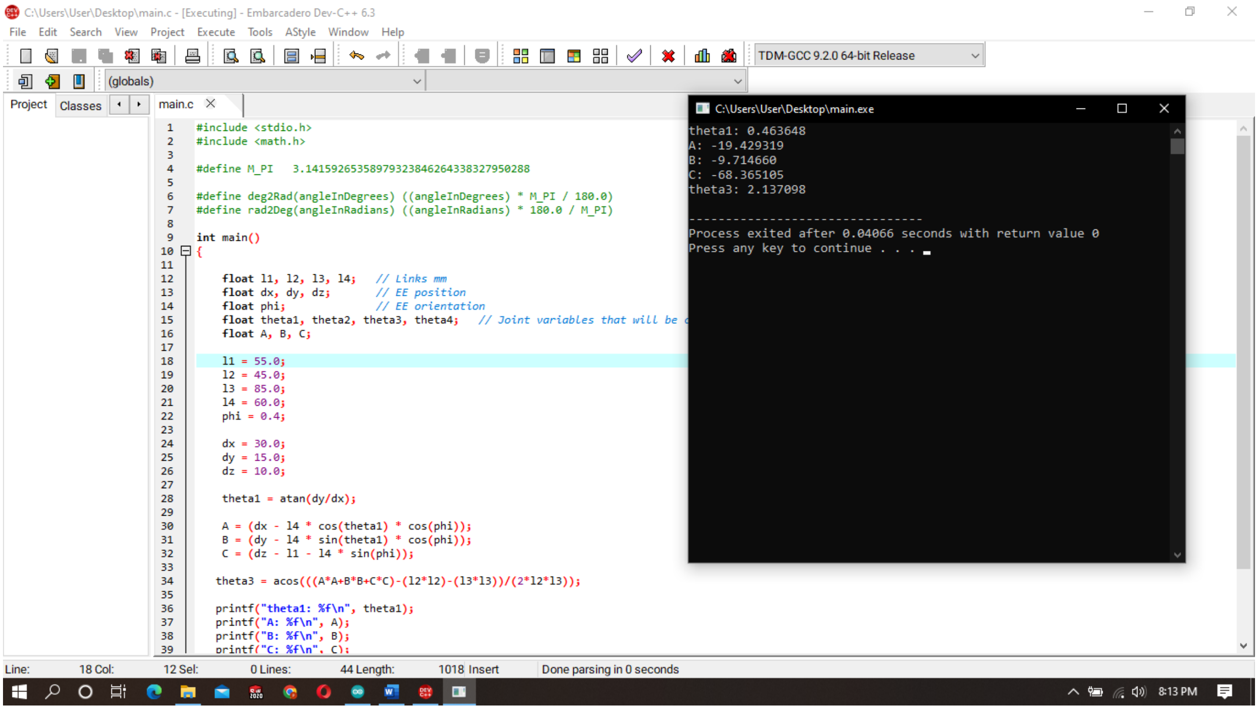


figure D-0-3 : kinematic calculation

Process of done using ROS, Moveit, Rviz and Arduino.

Import URDF to moveit

figure D-0-4: URDF import

Joints was defined

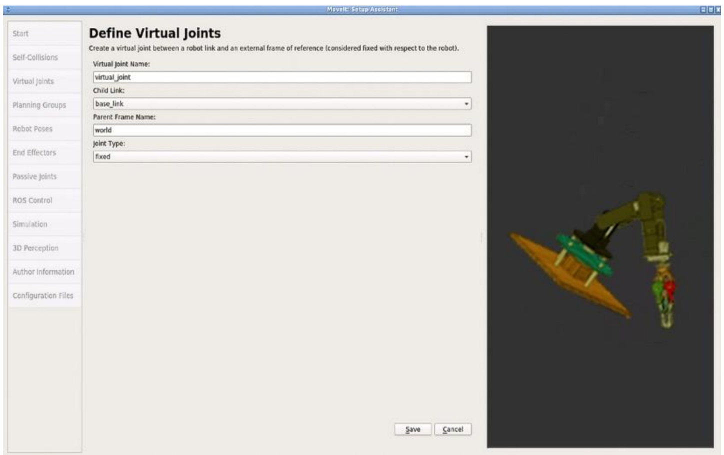


figure D-0-5 : joint defining

Robot poses was defined

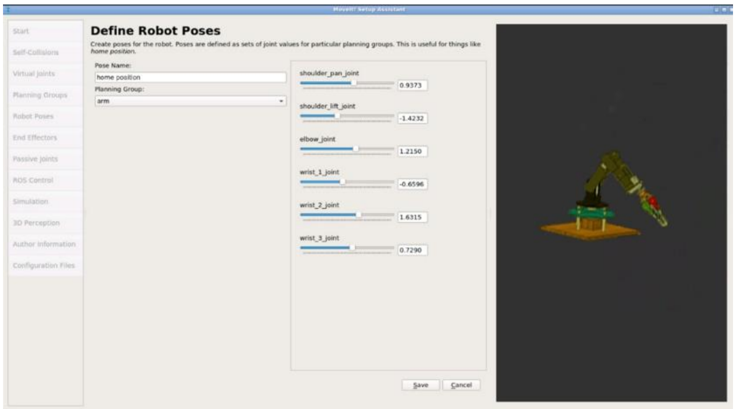


figure D-0-6 : poses defining

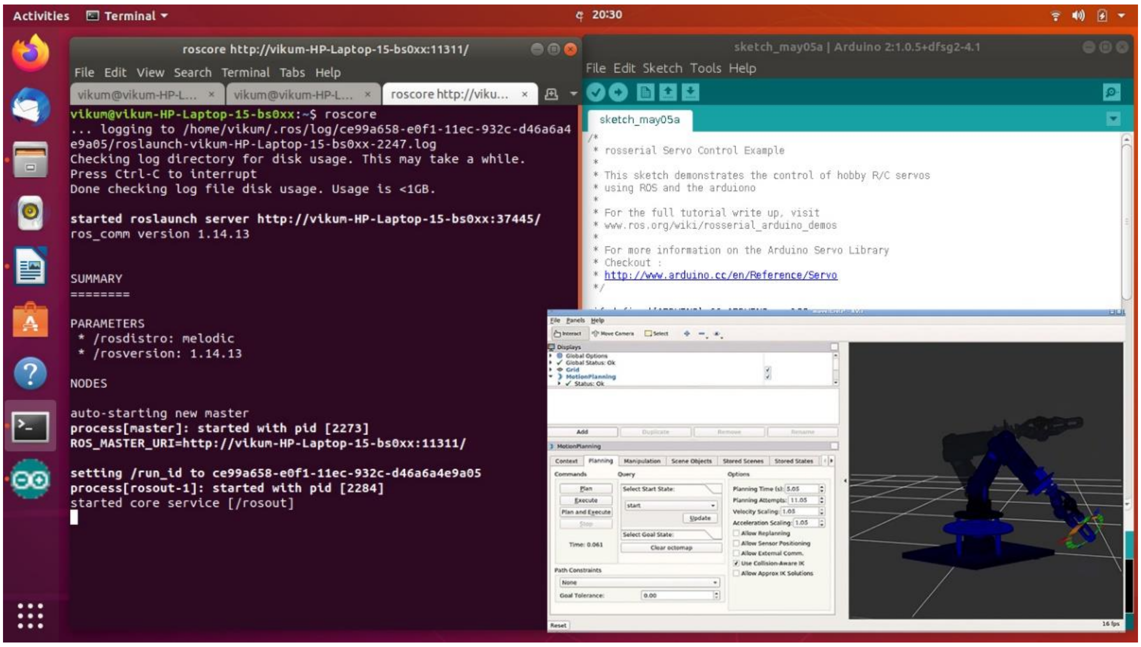


figure D-0-7 : all windows of platform

Appendix E

Redesigned robot manipulator

The design was redesigned without bugs in prototype. This was designed to avoid errors and to be used in the industry. Calculations were also made to select the motor to be used for this purpose.

3D CAD drawing of new design

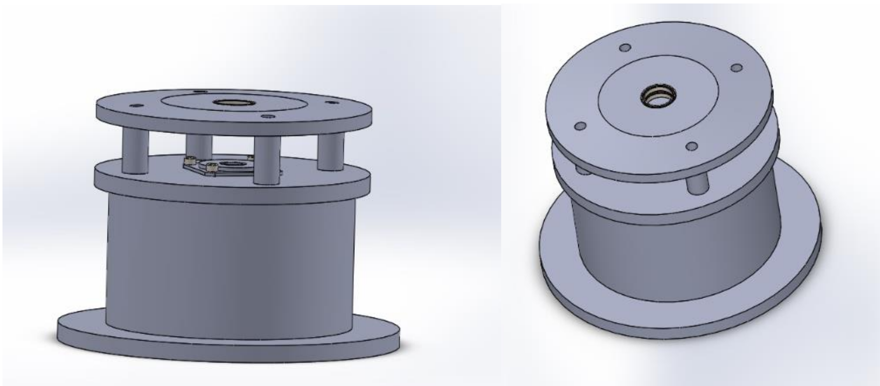


figure E-0-8 : base part of new design

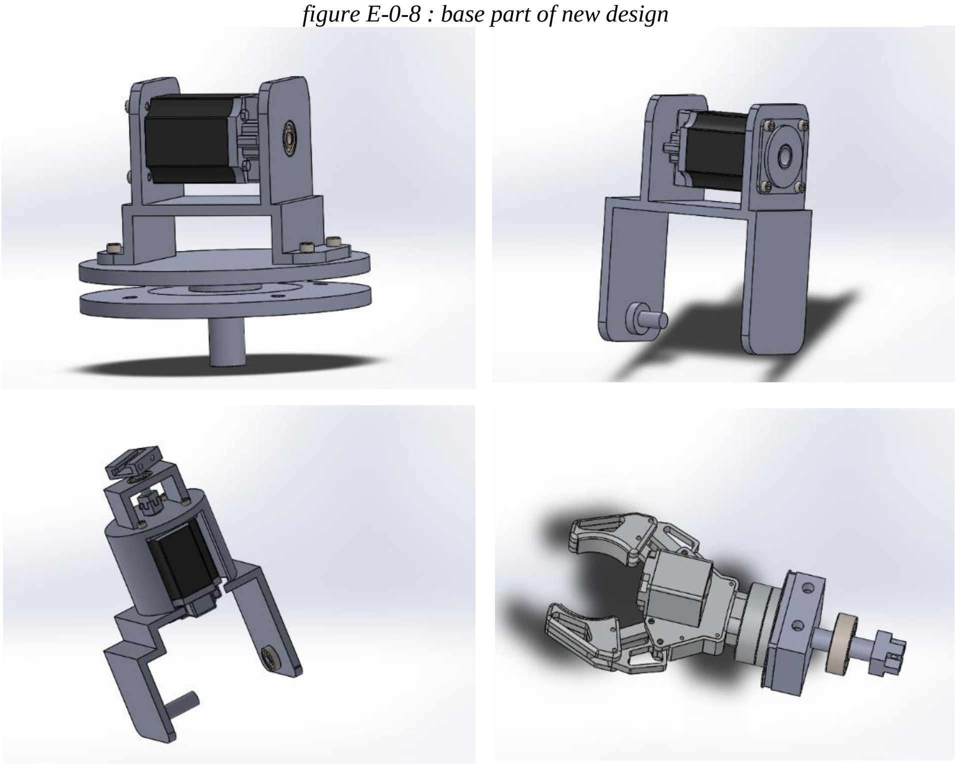


Figure E-14 : parts of new design

basic dimension of new design

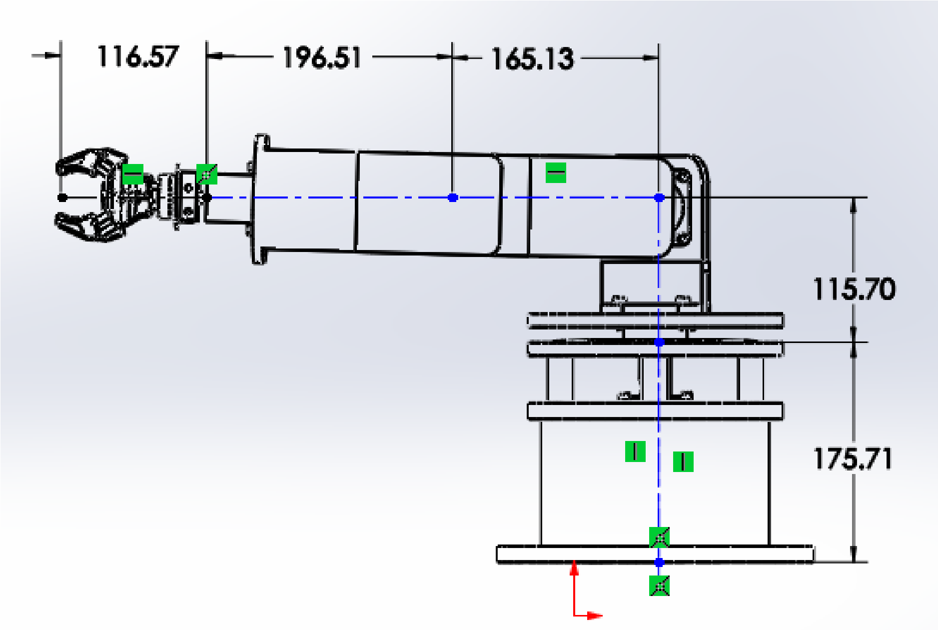


Figure E-15 : basic dimension of robot arm

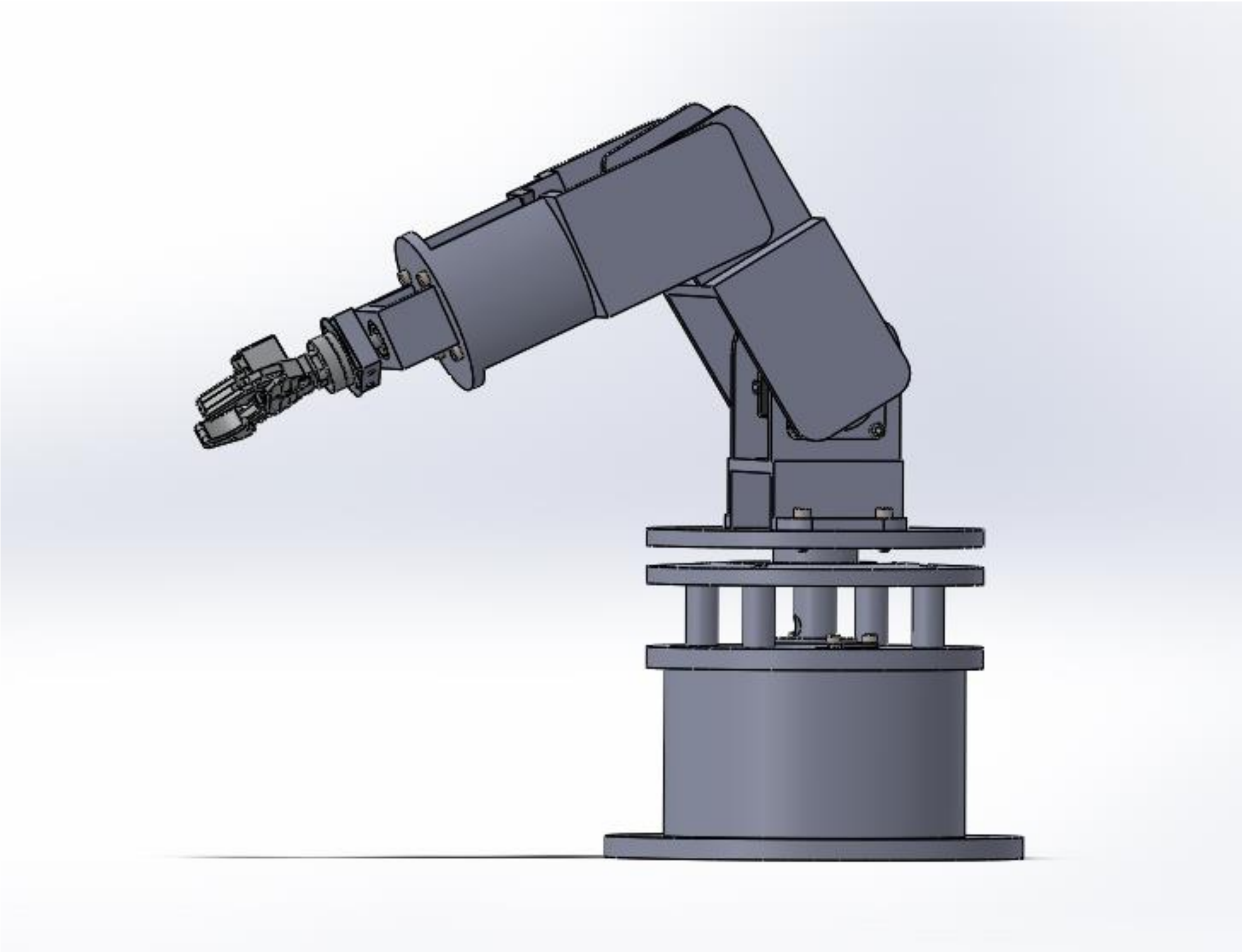


Figure E-16 : 3D view of robot arm

Changeable end effector parts of new design

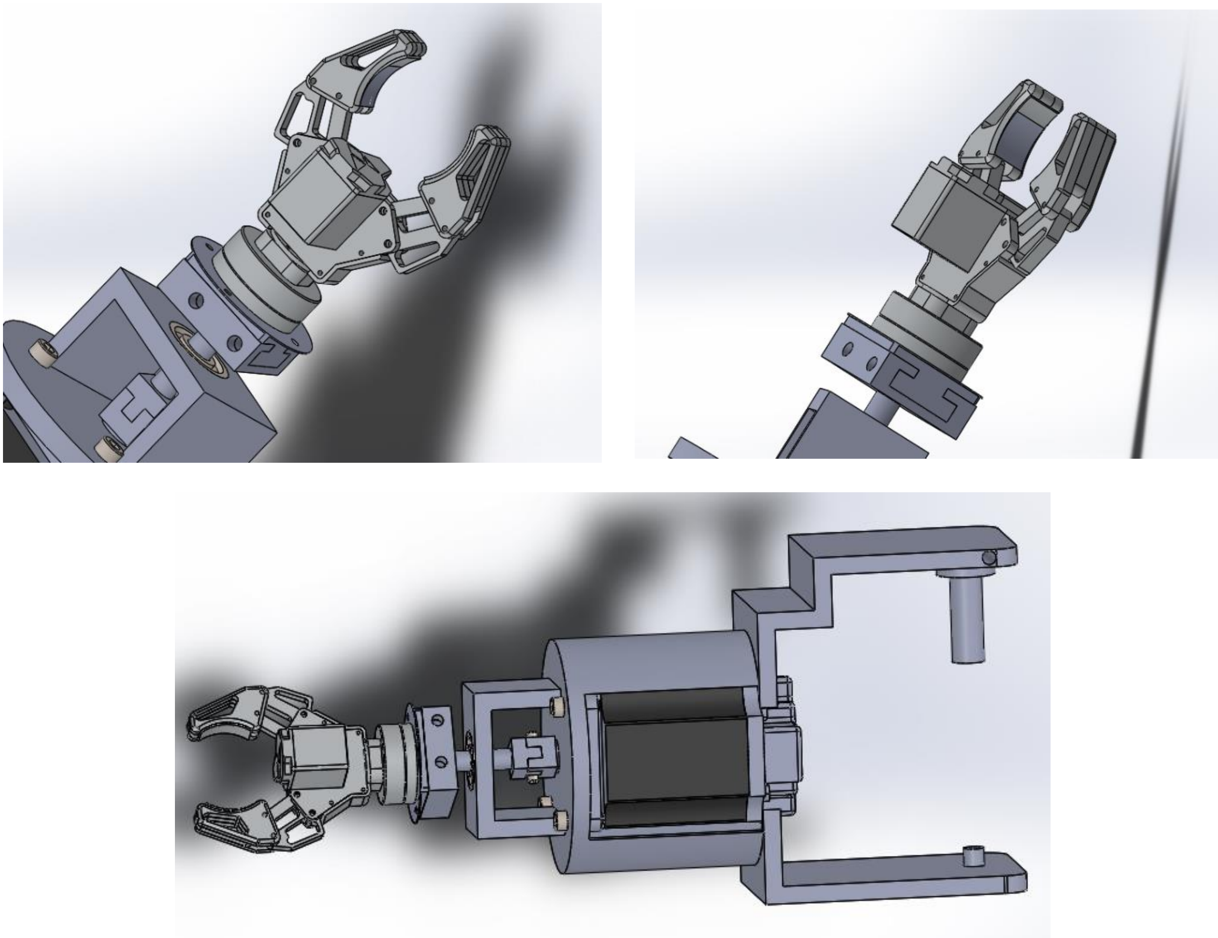


Figure E-17 : Changeable end effector parts of new design

Material Properties

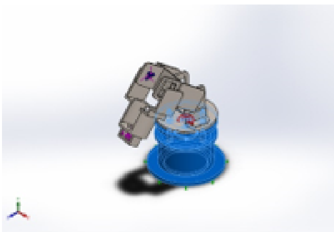
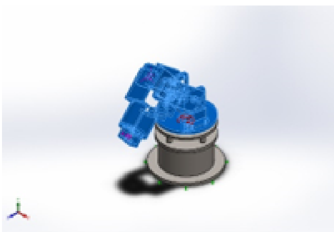
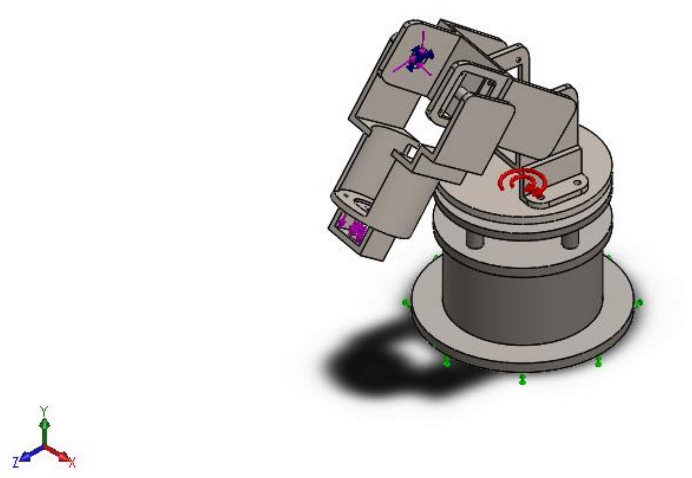
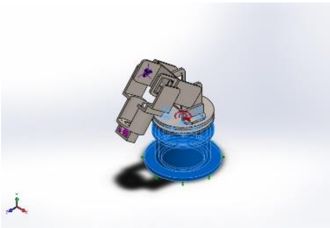
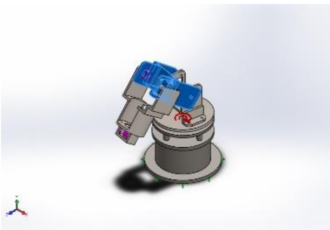
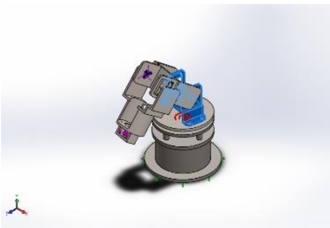
Model Reference	Properties
	Name: AISI 1035 Steel (SS) Model type: Linear Elastic Isotropic Default failure criterion: Max von Mises Stress Yield strength: 2.82685e+08 N/m^2 Tensile strength: 5.85e+08 N/m^2 Elastic modulus: 2.05e+11 N/m^2 Poisson's ratio: 0.29 Mass density: 7,850 kg/m^3 Shear modulus: 8e+10 N/m^2 Thermal expansion coefficient: 1.1e-05 /Kelvin
Curve Data:N/A	
	Name: Alumina Model type: Linear Elastic Isotropic Default failure criterion: Unknown Tensile strength: 3e+08 N/m^2 Compressive strength: 3e+09 N/m^2 Elastic modulus: 3.7e+11 N/m^2 Poisson's ratio: 0.22 Mass density: 3,960 kg/m^3 Shear modulus: 1.5e+11 N/m^2 Thermal expansion coefficient: 7.4e-06 /Kelvin

Figure E-18 : material properties



Model name: Assem20
Current Configuration: Default

Solid Bodies

Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Cut-Extrude8 	Solid Body	Mass:11.8039 kg Volume:0.00150368 m^3 Density:7,850 kg/m^3 Weight:115.678 N	G:\UOK\FCT\4 th year\project\25_05_2022 robot arm\base\Part3.SLDPRT May 29 11:48:40 2022
Boss-Extrude9 	Solid Body	Mass:1.18369 kg Volume:0.000298912 m^3 Density:3,959.99 kg/m^3 Weight:11.6002 N	G:\UOK\FCT\4 th year\project\25_05_2022 robot arm\2 axixs\arm.SLDPRT Jun 7 15:17:30 2022
Fillet9 	Solid Body	Mass:0.856969 kg Volume:0.000216406 m^3 Density:3,960 kg/m^3 Weight:8.3983 N	G:\UOK\FCT\4 th year\project\25_05_2022 robot arm\1 axixs\arm1.SLDPRT Jun 6 12:32:36 2022

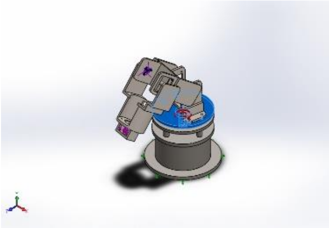
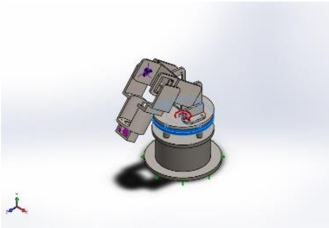
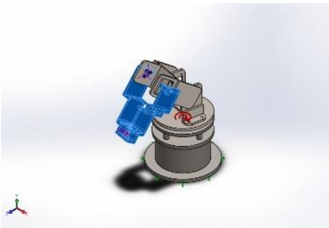
Cut-Extrude4 	Solid Body	Mass:1.4618 kg Volume:0.000369141 m^3 Density:3,960 kg/m^3 Weight:14.3256 N	G:\UOK\FCT\4 th year\project\25_05_2022 robot arm\base\base 1.SLDPRT Jun 7 07:33:32 2022
Cut-Extrude7 	Solid Body	Mass:2.86798 kg Volume:0.000365348 m^3 Density:7,850 kg/m^3 Weight:28.1062 N	G:\UOK\FCT\4 th year\project\25_05_2022 robot arm\base\base 2.SLDPRT Jun 7 15:47:13 2022
Boss-Extrude18 	Solid Body	Mass:1.32085 kg Volume:0.000333548 m^3 Density:3,960 kg/m^3 Weight:12.9444 N	G:\UOK\FCT\4 th year\project\25_05_2022 robot arm\end axixs\rownder part 2.SLDPRT Jun 9 05:45:26 2022

table E-1 : solidwork report details 1

Appendix F

calculation for motor selection

Need to find the torque required for each motor for select the motors. Calculations are don for this.

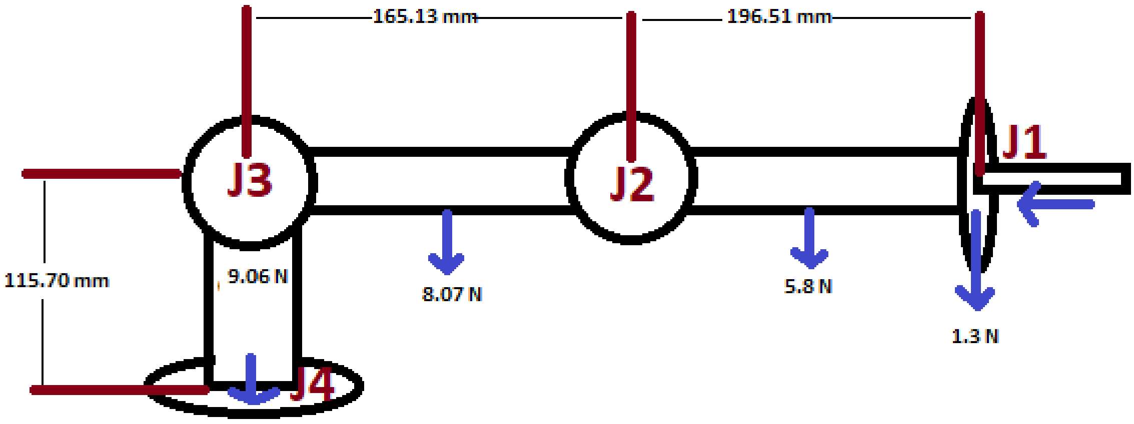


Figure F-1 : dimension for calculation

The maximum lifting weight for all calculations are assume 2 Kg (20N)

For joint 1

(Assume total force parallel into the twisted joint)

$\tau = FR$

J_3 = 21.3N x 0.1157m

Theoretical torque of J_3 = 2.464Nm

Bearing loss = 10%

J_3 = 2.464Nm x $\frac{110}{100}$ = 2.7104Nm

Torque with safety factor (3)

$\underline{\underline{J_3 = 2.7104\text{Nm x } 3 = 8.1\text{Nm}}}$

For joint 2

$\tau = FR\cos\varnothing$

J_2 = (5.8N x 0.19651m x 1) + 2.464Nm

Theoretical torque of J_1 = 3.603Nm

Gear head loss = 10%

Bearing loss = 8%

Friction loss = 8%

Dynamic (Inertia) loss = 10%

Torque with losses

J_2 = 3.603Nm x $\frac{136}{100}$ = 4.908Nm

Torque with safety factor (2)

$\underline{\underline{J_2 = 4.908\text{Nm x } 2 = 9.96\text{Nm}}}$

For joint 3

$\tau = FR\cos\varnothing$

J_2 = (8.07N x 0.16513m x 1) + 3.603Nm
Theoretical torque of J_1 = 4.962Nm
Gear head loss = 10%
Bearing loss = 8%
Friction loss = 8%
Dynamic (Inertia) loss = 10%
Torque with losses
J_2 = 4.962Nm x $\frac{136}{100}$ = 6.748Nm
Torque with safety factor (2)
$\underline{\underline{J_2 = 6.748\text{Nm} \times 2 = 13.49\text{Nm}}}$

Base point
(Assume total force parallel into the twisted joint)
$\tau = FR$
J_3 = (9.06N + 8.07N + 5.8N + 1.3N + 20N) x 0.115m
Theoretical torque of J_3 = 5.086Nm
Bearing loss = 10%
J_3 = 5.086Nm x $\frac{110}{100}$ = 5.594Nm
Torque with safety factor (3)
$\underline{\underline{J_3 = 5.594\text{Nm} \times 3 = 16.78\text{Nm}}}$

For J1	: ATO130ST-M10010 (1KW | 4/10Nm | 2500 rpm)
For J2	: ATO130ST-M10010 (1KW | 4/10Nm | 2500 rpm)
For J3	: ATO110SY-M05030 (1.5KW | 5/15Nm | 3000 rpm)
Base point	: ATO130SY-M10010 (1KW | 10/25Nm | 1000 rpm)

Appendix G

PLC and HMI program

PLC program

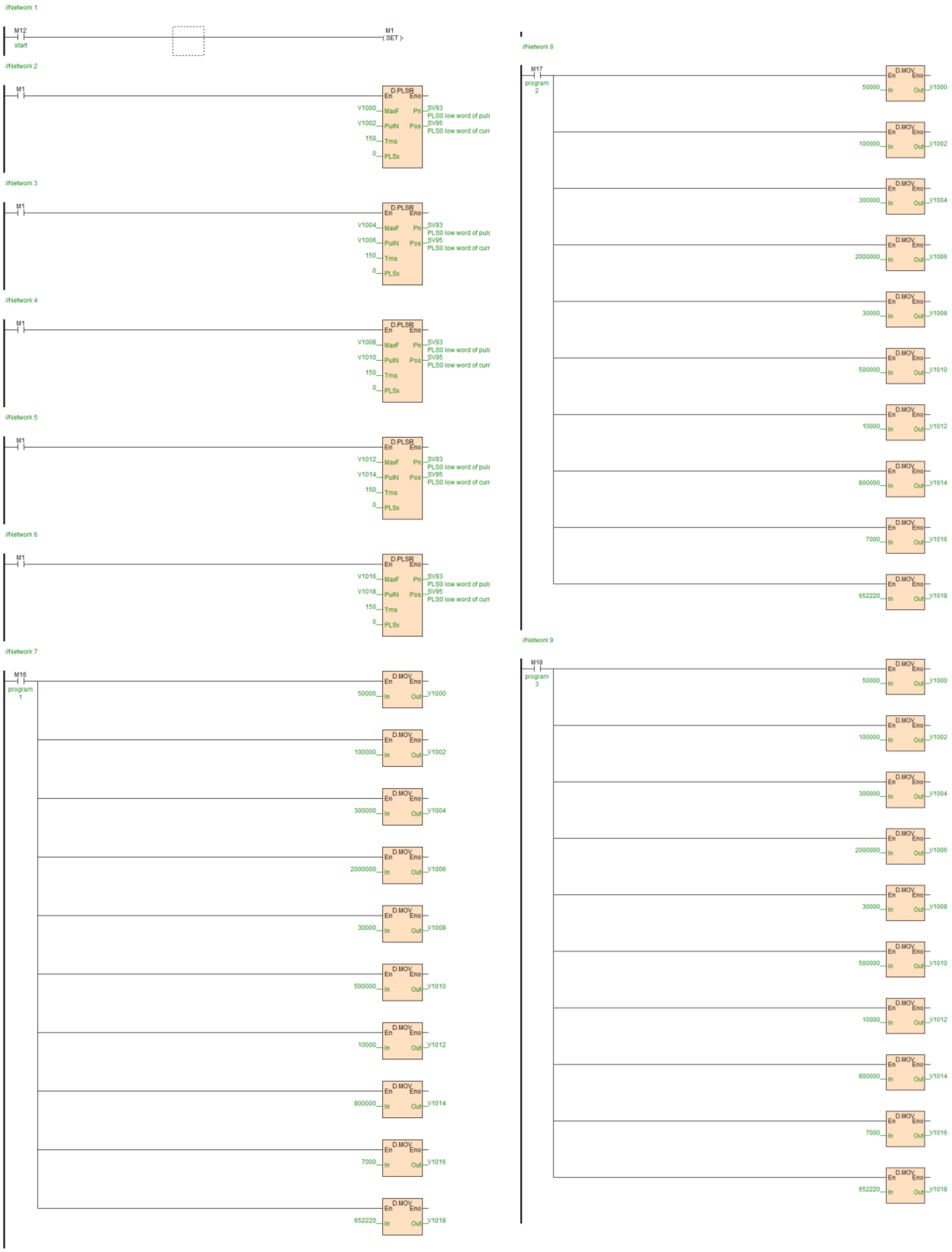


Figure G-1 : PLC program

HMI panel

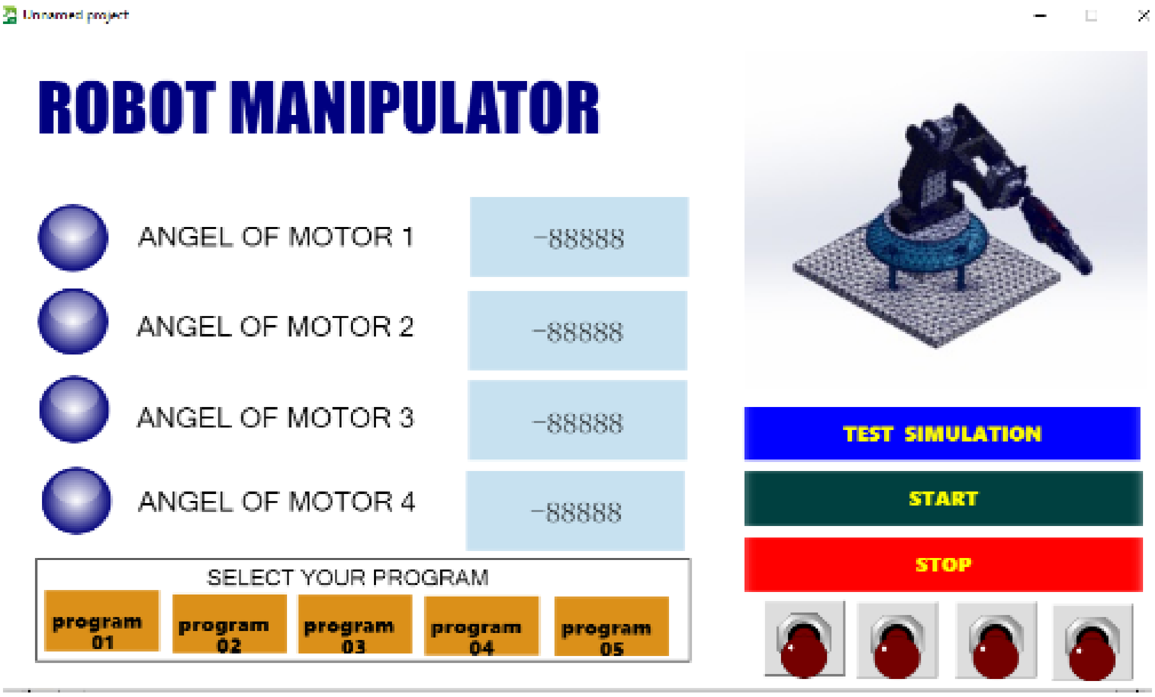


Figure G-2 : HMI panel

Appendix H

MG 945 servo motors are used this prototype

Figure H-1 : MG 945 servo motor

Specifications

Modulation:	Digital
Torque:	**4.8V:** 138.87 oz-in (10.00 kg-cm) **6.0V:** 166.65 oz-in (12.00 kg-cm)
Speed:	**4.8V:** 0.23 sec/60° **6.0V:** 0.20 sec/60°
Weight:	1.94 oz (55.0 g)
Dimensions:	**Length:**1.60 in (40.7 mm) **Width:**0.78 in (19.7 mm) **Height:**1.69 in (42.9 mm)
Motor Type:	Servo motor
Gear Type:	Metal
Rotation/Support:	Dual Bearings
Rotational Range:	180^0
Pulse Cycle:	1 ms
Connector Type:	JR

Table H-1: specification of MG 945 [33]