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Faculty of Technology Lappeenranta
Mechanical Engineering and Production Technology

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Theory of Robotics Arm Control with PLC

Thesis 2015

Abstract

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This thesis was commissioned for Saimaa University of Applied Sciences with the aim of understanding the control system for a robotic arm. The Robotic Arm in this case was from Saimaa University of Applied Sciences.

The main objective of this thesis was to understand a control system for the Robotic Arm using a programmable logic controller (PLC) along with gripper. The control system consisted of the electronic components (the PLC, a motor controller, a voltage regulator, a control pendent and a bride board circuit).

The Robotic Arm works manually using potentiometers and also with the help of PLC. At the beginning, studies were carried out to define the design constraints for finding the best options among components that are most suitable for this application. A control system with a PLC needs additional electronic components, such as a DC motor controller and control pendant. The parts selected are those that met the specifications requirements. The majority of the time is spent on understanding wiring and installation. During the installation, consideration is made for a safe and effective process. In this work, for the design of the gripper, only the research and theoretical design approach is made. After the complete theoretical installation of all the hardware sections, the theoretical programming is the last to be completed. The principles for manual modes of operation and automatic modes of operation are described in detail in the programming part of this thesis.

All the parts of the control system; i.e. the hardware part and the programming part are accomplished with a successful theoretical demonstration.
The complex programming is possible in the PLC for the automatic mode of operation. It is found that a Robotic Arm with a simple mechanism can be manipulated in a different complex way by using a PLC.

Keywords: Robotic Arm Manipulator, PLC, Motor Controller, Potentiometer

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1. Introduction

In the industrial world, automation is one of the most important elements for development. It helps 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.

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). 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.

This thesis is a theoretical based thesis. Additionally, the necessary research is done to evaluate the best solution of the problem which is part of the thesis. The project includes the following objectives:

- Comparing the available components from the market which meet the best solution. i.e. (PLCs), Motor controllers, Grippers, DC motors etc.
- Designing a layout for the installation of PLC, a Robot and other components together.
- Wiring Design and wiring installation
- Designing and construction of a bridge board circuit, a voltage regulator circuit, a control pendent, a wiring rail and a DC motor driver support system
- Designing the gripper
- Programming
- Testing and Finalizing
- Documenting

2. Background of the Thesis

The topic of this thesis is chosen to understand robotics arm motion placed in Saimaa University of Applied Sciences Laboratory with the aim to get knowledge about the complete control system for a robotic arm. In this project, the control system refers to the development of a system which controls the automatic movements and accurate positioning of the robotic arm. And this also includes the functioning of a gripper as an end effector. During this process, a student is supposed to use his engineering knowledge. This thesis includes various aspects of Mechanical Engineering; automations (control system), forms of electronic drives, general engineering subjects, parts design (strength of materials) and mathematics etc. The result is that this thesis also helps to develop the skills of practical knowledge about the subject matter in real life.

2.1 Robotic Arm

The Robotic Arm shown in Figure 2.1 below is from the Saimaa laboratory. This robot has five axes which are driven by DC motors (24Vdc) and it is made to be controlled manually by using sets of two potentiometers for each joint. To control a single joint, two potentiometers are used connected to each other in a feedback amplifier circuit. The comparator circuit compares the voltage between the axis potentiometer and the driver potentiometer, and it drives the motor in two directions depending on the voltage between these two potentiometers.

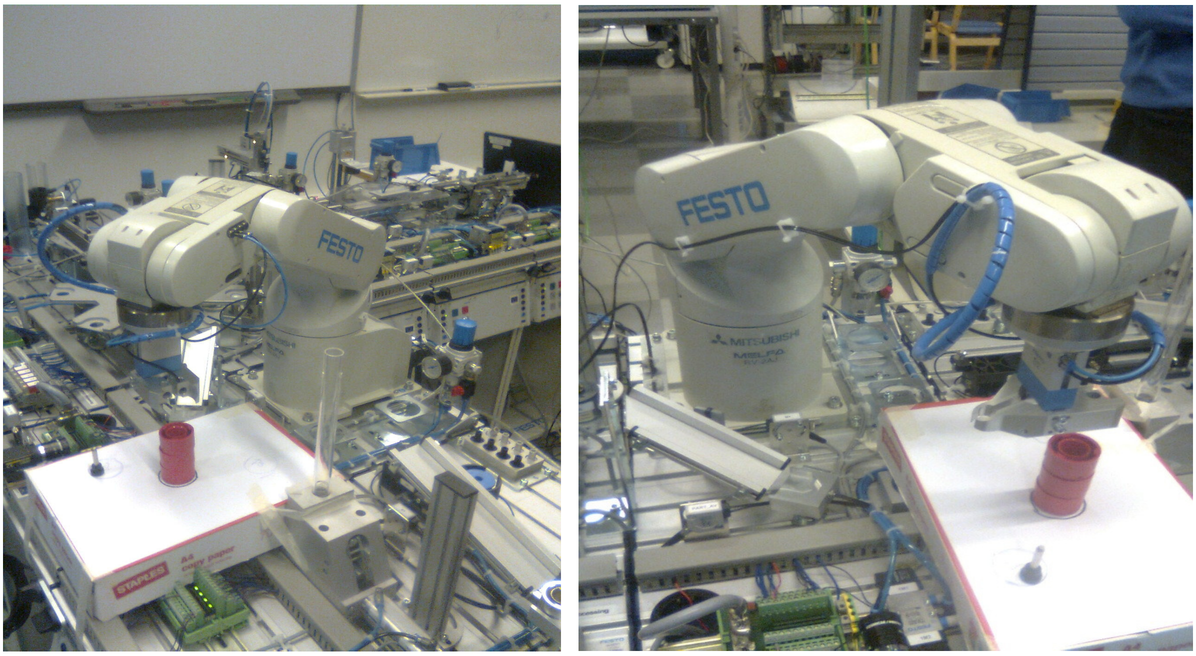


Figure 2.1 Robotics Arm

2.2 Working Mechanism

The output voltage for driving the motor depends upon the two potentiometers voltage value: the driving potentiometer and the axis potentiometer. Two potentiometers are integrated into the feedback amplifier circuit. The driving potentiometer voltage works like an input voltage and it can be set by the user whereas the axis potentiometer works like feedback voltage, altering the output. The axis potentiometer voltage depends upon the position of the axis and its changes due to the rotation of the axis. When the input voltage and feedback voltage are in the same phase, then the output becomes positive and it drives the motors in a positive direction until the input voltage (driving potentiometer) and the feedback voltage (axis potentiometer) have the same voltage value. When the input voltage and feedback voltage are in the inverse phase, then the output becomes negative and it drives the motors in a negative direction until these voltages are the same. In every case, the direction of the motor is set in such a way that it rotates to change the voltage of the axis potentiometer the same as the driving potentiometer voltage and then the motor stops.

3. Main Components

The component design requirement is set according to the need of this thesis. In this part, the main basic requirements are the process of the control system and the gripper design. Both of them have completely different requirements which consist of the physical components and their features. On the basis of these features, the selection is made out of these components which meet the required criteria. For each component, a short introduction and products specification is given.

3.1 Programmable Logical Controllers (PLC)

A programmable logic controller (PLC) is a type of digital computer that has an input and an output interface, controlled by a simulated program designed in a computer and it is used for automation for electromechanical process, typically for industrial use. In industry, PLCs are made to control the machinery of production lines. A PLC is designed for multiple input and output arrangements and these inputs and outputs are logically programmed in different forms, such as a ladder diagram, a structural text and a functional block diagram and stored in the PLC's memory. PLCs are reprogrammable and they can have monitors online to know the status of the operation.

A PLC is an example of a hard real time system since output results must be produced in response to input conditions within a limited time, otherwise an unintended operation will result. Figures 3.1 and 3.1.1 below show a typical old type 8 inputs PLC and automation system SIMATIC S7-300.

Figure 3.1 A typical PLC with 8 inputs and 4 outputs and Ethernet connection

(https://www.google.com/search?hl=fi&site=imghp&tbm=isch&source=hp&biw=1280&bih=856&q=PLC&oq=PLC&gs_l=img.3..0l4j0i30l6.5239.5847.0.6613.3.3.0.0.0.0.64.171.3.3.0.msedr...0...1ac.1.64.img..0.3.167.jf4KsNkxFDg)

Figure 3.1.1 Automation system SIMATIC S7-300 ***(Siemens Product Specification, 2003)***

3.2 DC Motor Controller

A motor controller is a device or a group of devices that serves to govern in some predetermined manner the performance of an electric motor. A motor controller might include a manual or automatic means for starting and stopping the motor, selecting forward or reverse rotation, selecting and regulating the speed, regulating or limiting the torque, and protecting against overloads and faults.

For this application, the two base motors axes have a large amount of load because of the heavy arm and to drive motor smoothly a motor controller is needed. During starting and stopping, the motor controller helps to accelerate and decelerate the motor in a predefined speed to avoid damage and inaccuracy. Also the reason is that, the PLC analog output interface current is not sufficient to operate the motors. Depending upon the task, the motors are driven at defined speeds and directions which can be easy controlled using the motor controller.

The requirements of the motor controllers have the following specifications:- Supply voltage

Over volt. Protect.	30v
Speed setting input	0 to 10 V or -10 V to 10 V
Control Power	100 watt minimum
Motor Voltage	0-15 (12V range)
	0-29 (24V range)
Number of motor control	As many as possible

3.3 DC Motors

A DC motor is an electric motor that runs on direct current (DC). A DC motor is used for driving the axis of the robot. The axis of the arm needs a larger amount of torque than the nominal torque which is supplied by the DC motor in its nominal speed. So, the torque of the motor is amplified with the help of a gear system which is embedded in the DC motor. The Figure below shows a Dayton DC Gear motor.

In this control system, the motor will run in both directions and in certain applications with variable speeds. Figure 3.3 below shows a Dyton DC gear motor.
Nominal voltage +12V; +24V
Nominal power 40W-100W;
Nominal current +2A…. 4A

Figure 3.3 Dayton DC Gear motor *(Dyton)*

(https://www.google.com/search?hl=fi&site=imghp&tbm=isch&source=hp&biw=1280&bih=856&q=PLC&oq=PLC&gs_l=img.3..0l4j0i30l6.5239.5847.0.6613.3.3.0.0.0.0.64.171.3.3.0.msedr...0...1ac.1.64.img..0.3.167.jf4KsNkxFDg#hl=fi&tbm=isch&q=DC+motors)

3.4 Potentiometer

A typical single-turn potentiometer is shown in Figure 3.4 below. A potentiometer is a three terminal resistor with a sliding contact that forms an adjustable voltage divider for measuring the electric potential (voltage). It is commonly used in many electrical devices such as volume controls in audio equipment, position transducers, signal adjustment etc.

Figure 3.4 A typical single-turn potentiometer *(Wikipedia)*

(https://www.google.com/search?hl=fi&site=imghp&tbm=isch&source=hp&biw=1280&bih=856&q=PLC&oq=PLC&gs_l=img.3..0l4j0i30l6.5239.5847.0.6613.3.3.0.0.0.0.64.171.3.3.0.msedr...0...1ac.1.64.img..0.3.167.jf4KsNkxFDg#hl=fi&tbm=isch&q=potentiometer)

4. Functional Description

A simple method for the movement of a Robotic Arm can be monitored and controlled by using a potentiometer. This system is built to control every joint movement manually. The shaft of a potentiometer is attached to the shoulder or elbow joint or motor. As the joint rotates, it turns the shaft of the potentiometer which changes the resistance; this change in resistance indicates the precise position of the joint. In our conditions, the Robotic Arm has all the rotating joints so the rotary potentiometers were for every joint. The rotary potentiometers have the limitation of angular freedom. Typically it has about a 0°-280° rotation angle which is sufficient to move the Robotic Arm all directions. Figure 4.1 below shows the positioning system using potentiometer.

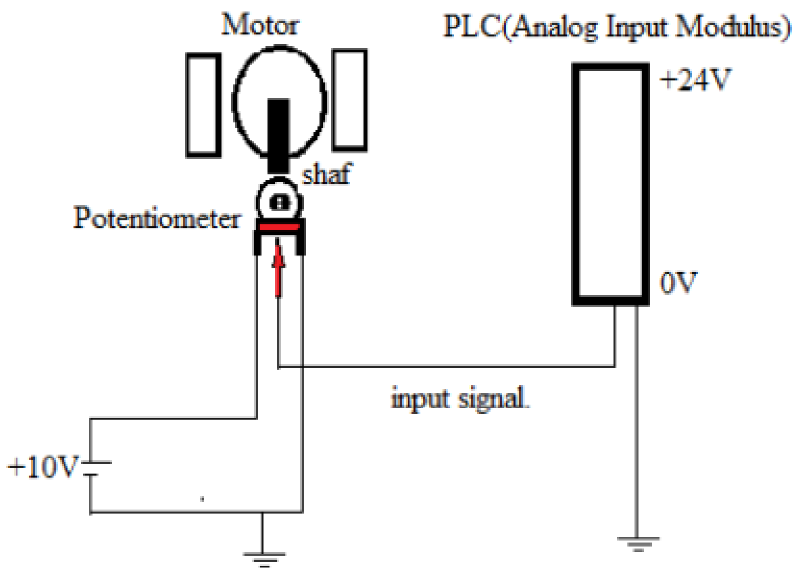


Figure 4.1 Positioning system using potentiometer

A constant voltage of +10Vdc is connected for each of the potentiometers and the position of the arm is given in an analog form, i.e. voltage. The analog value of voltage is converted to digital bits by the PLC and the calculation is done on the basis of the digital values. Figure above shows the working principle.

The axis of the Robotic Arm is driven by DC motors and each DC motor has a potentiometer attached to the gear axis so that the potentiometer revolves as the motor rotates. The potentiometer gives a certain value of voltage as a feedback which is used to detect the position of that particular motor. The analog input voltage is converted to digital value and is saved as the position of the point. It is done for each point of the potentiometer. A set of analog values from all the potentiometers is saved in the PLC as a digital number and this set of digital numbers gives the position and direction of the arm.

The saved digital number is now converted to an analog output voltage which is connected to a comparator. The comparator compares the input voltage from the potentiometer and the output voltage from the PLC to control the motor and the motor is stopped only when both voltages are the same. With the help of the comparator, the motor is driven to the position where it should be. Depending upon the task, the Robotic Arm is then programed to move to every position in sequence and performs the gripping and releasing task.

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. There are two terms in robotics which define the methods used for calculations: forward kinematics and inverse kinematics.

Forward kinematics refers to the use of the kinematic equations of a robot to compute the position of the end-effector from specified values for the joint parameters.

Inverse kinematics refers to the use of the kinematics equations of a robot to determine the joint parameters that provide a desired position of the end-effector "This method is comparatively harder than forward kinematics, as it has more than one solution for a particular point".

4.1 Mathematical Background

A standard mathematic tool used in robotics for computing the position and orientation of the end effecter is Denavit-Hartenberg parameters which is also called DH parameters. DH parameters help to define the constraints between the links of the two joints. For any joint, there are four different parameters defined as DH parameters. Figure 4.1.1 shows the constraints of DH parameters.

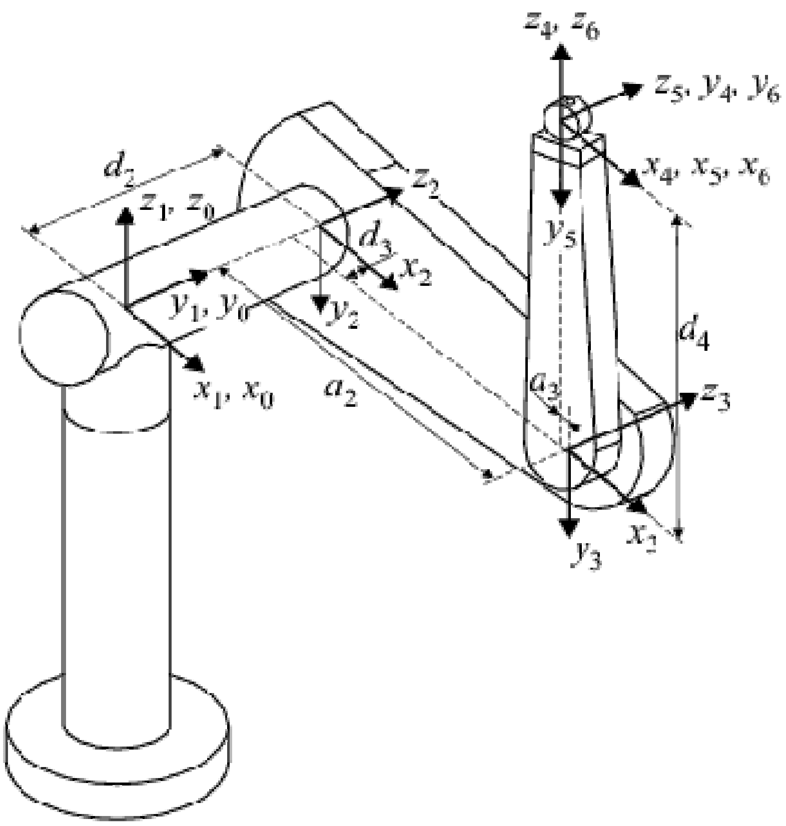


Figure 4.1.1 Constraints of DH parameters *(Lavalle, 2006)*

a1 = perpendicular distance between axis (Zi, Zi+1) along Xi

α = angle between the Zi and Zi+1 about Xi

di = Distance between (Xi-1, Xi) along Zi

Ɵi = angle (Xi-1, Xi) about Zi

For every joint, among these four parameters, only two of them are variables; di for the prismatic joint (linear joint) and Ɵi for the rotatory joint. In the current case, the robot only has rotatory joints, so the value of di = 0 in every case and Ɵi is the only variable.

To make the solution for our robot arm, firstly the DH parameters must be defined using the free body diagram (FBD) of the robot arm. The FBD diagrams can be drawn as shown. (M LaValle 2012). Figure 4.1.2 below shows the dimension of the Robotic Arm.

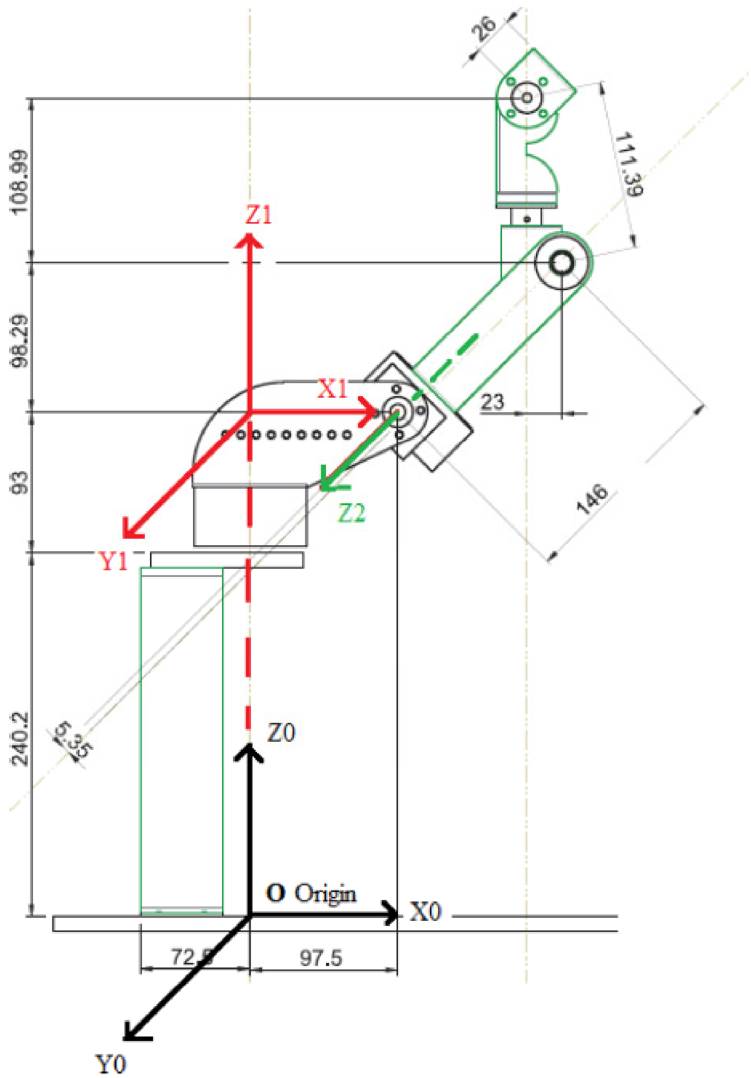


Figure 4.1.2 Dimension of the Robotic Arm

The six angular variables can define the orientation and position of the end effectors. The Denavit-Hartenbert convention has a set of rule to define these parameters by using the standard representation in FBD. This FBD defines the natures and constraints of the joints. Each joint has its own coordinates system which can be defined in respect to the nearby joint's coordinates. The free body diagram (FBD) of the Robotic Arm can be drawn as shown in Figure 4.1.3 below.

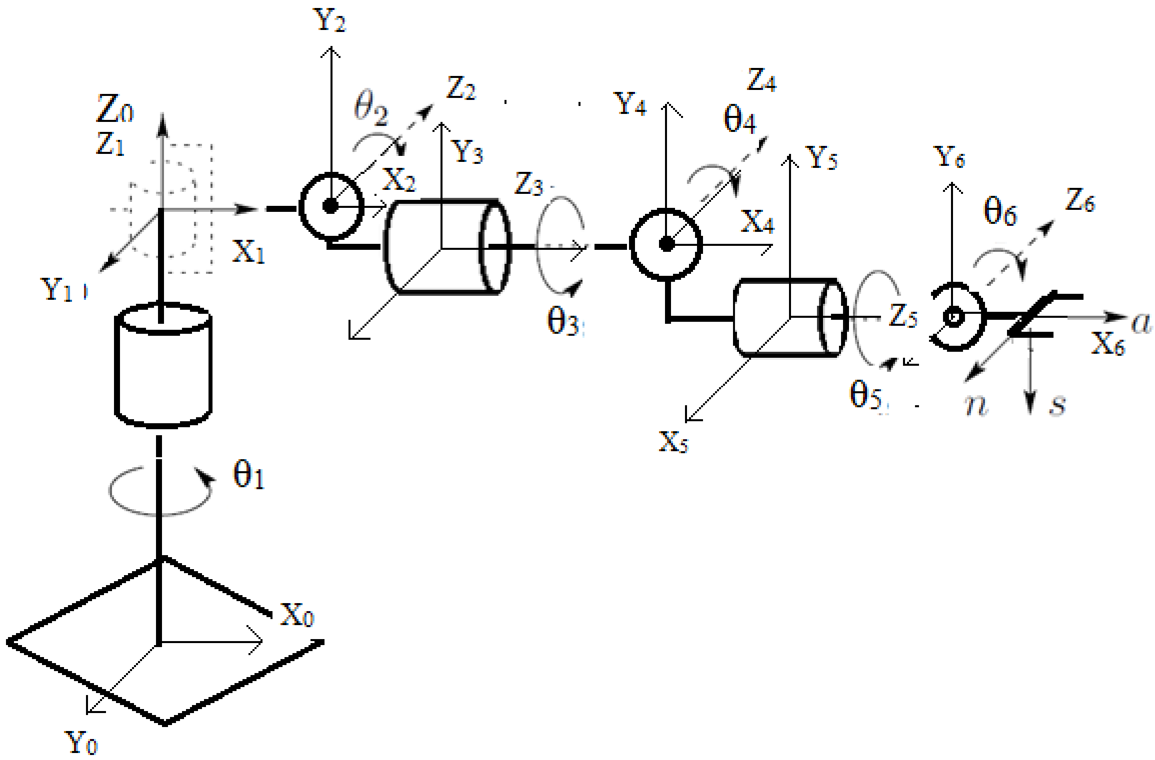


Figure 4.1.3 Free Body Diagram (FBD) defining DH parameters

The transformation matrix for each joint can be formed using the given formula in Figure 4.1.4 below.

$$\begin{bmatrix} \cos\theta_i & -\sin\theta_i & 0 & a_{(i-1)} \\ \sin\theta_i\cos\alpha_{(i-1)} & \cos\theta_i\cos\alpha_{(i-1)} & -\sin\alpha_{(i-1)} & -\sin\alpha_{(i-1)}d_i \\ \sin\theta_i\sin\alpha_{(i-1)} & \cos\theta_i\sin\alpha_{(i-1)} & \cos\alpha_{(i-1)} & \cos\alpha_{(i-1)}d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_2(\theta_2) = \begin{pmatrix} \cos\theta_2 & -\sin\theta_2 & 0 & 0 \\ 0 & 0 & 1 & d_2 \\ -\sin\theta_2 & -\cos\theta_2 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}, \quad T_3(\theta_3) = \begin{pmatrix} \cos\theta_3 & -\sin\theta_3 & 0 & a_2 \\ \sin\theta_3 & \cos\theta_3 & 0 & 0 \\ 0 & 0 & 1 & d_3 \\ 0 & 0 & 0 & 1 \end{pmatrix},$$

$$T_4(\theta_4) = \begin{pmatrix} \cos\theta_4 & -\sin\theta_4 & 0 & a_3 \\ 0 & 0 & -1 & -d_4 \\ \sin\theta_4 & \cos\theta_4 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}, \; T_5(\theta_5) = \begin{pmatrix} \cos\theta_5 & -\sin\theta_5 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -\sin\theta_5 & -\cos\theta_5 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix},$$

$$T_6(\theta_6) = \begin{pmatrix} \cos\theta_6 & -\sin\theta_6 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ \sin\theta_6 & \cos\theta_6 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}. \; T_1(\theta_1)T_2(\theta_2)T_3(\theta_3)T_4(\theta_4)T_5(\theta_5)T_6(\theta_6)\begin{pmatrix} x \\ y \\ z \\ 1 \end{pmatrix}.$$

Figure 4.1.4 Matrix equation for Robotics Joints

(http://planning.cs.uiuc.edu/node111.html)

The unknown angular values can be detected by the potentiometer reading for every joint. The potentiometer sent the analog voltage value which is converted to a digital value inside the PLC. The value of the potentiometer is calibrated to a real angle value and set in the PLC for the programming. For every point in space, the PLC detected the six different angular values and substitutes these angular values in the above equation to get the coordinates of that point in respect to the fixed frame.

The mathematical model for positioning the robot arm is very complicated. In our case, to control a robot using this mathematic model seems almost impossible. It forms 4 x 4 matrixes, which have a combination of variables which makes the equation lengthy. The industrial PLC has very limited programming features. And to solve the equation which contains trigonometry, it is very hard to make the program in the PLC.

4.2 Alternative Solution A

The PLC program can use the analog voltage value from the potentiometer and record every angular position. The particular angular value is memorized in the PLC as a digital number. To follow the previous position, the axis will rotate until the memorized digital value is the same. This process takes parallel to every axis and it defines a position and orientation of the end effectors in the space. A sequence of automatic movement is done using this memorized position in the PLC.

The use of the DC motor controller helps to reduce the compilation in controlling the speed and direction of the motor. This is the most effective way of controlling the DC motor. The motor controller is designed to give the amplification to signal, precision, direction change and safety. Depending upon the manufactures, the motor controller has different features. For this application, the motor controller must have the basic requirements.

Basic Requirement

Voltage: <24V>, Current: 3Amp, Power: 100W

Speed and direction control: analog output (±10V, ±5V, 1….10V) or Digital output (3…..30V). Figure 4.2.1 below shows the use of DC motor controller.

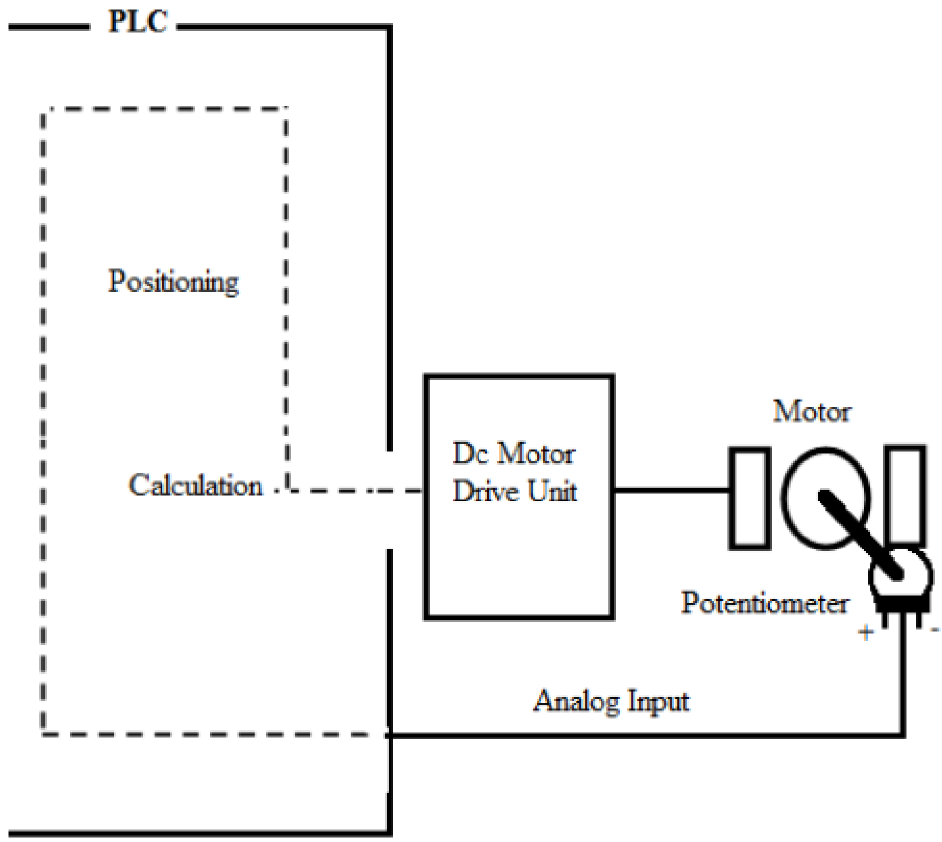


Figure 4.2.1 Diagram showing the use of DC motor controller

4.3 Alternative Solution B

This method for controlling the position of the arm is similar to the one which is described above. Instead of DC motor controller, in this method, a power amplifier is used. For driving the motor, the analog output is power amplified. Figure 4.3.1 below shows the use of Power Amplifier. The amplification is linear to the analog output signal. This amplifier is capable of accelerating and decelerating the motor according to the output signal value.

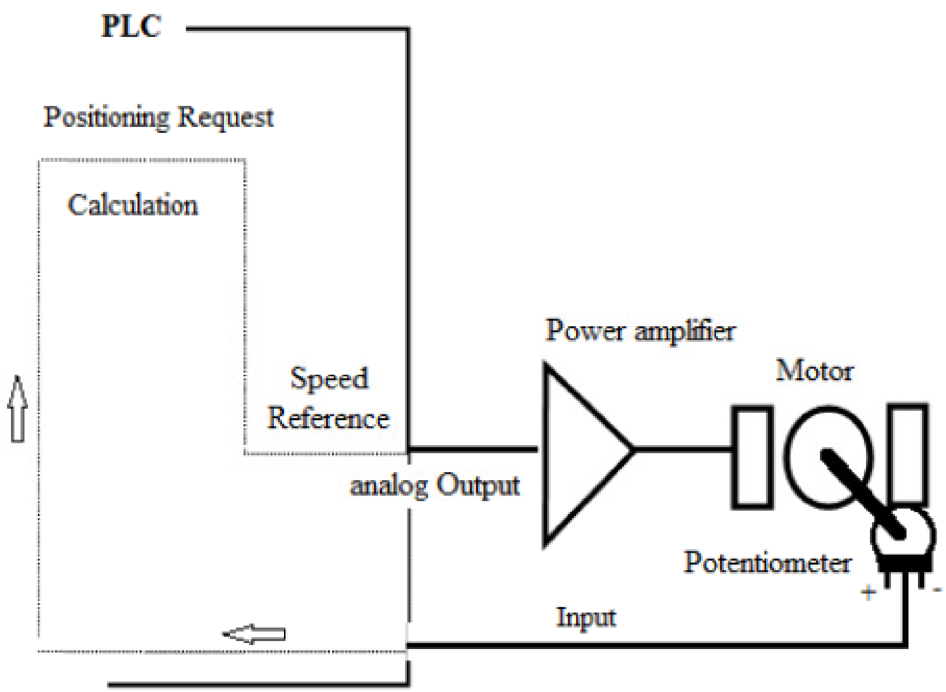


Figure 4.3.1 Diagram showing the use of Power Amplifier

5. System Description

The figure below shows the layout connection between the components. The hardware components for this control system are designed to operate in the automatic modes and the manual modes. Figure 5.1 shows the layout of all the connecting components.

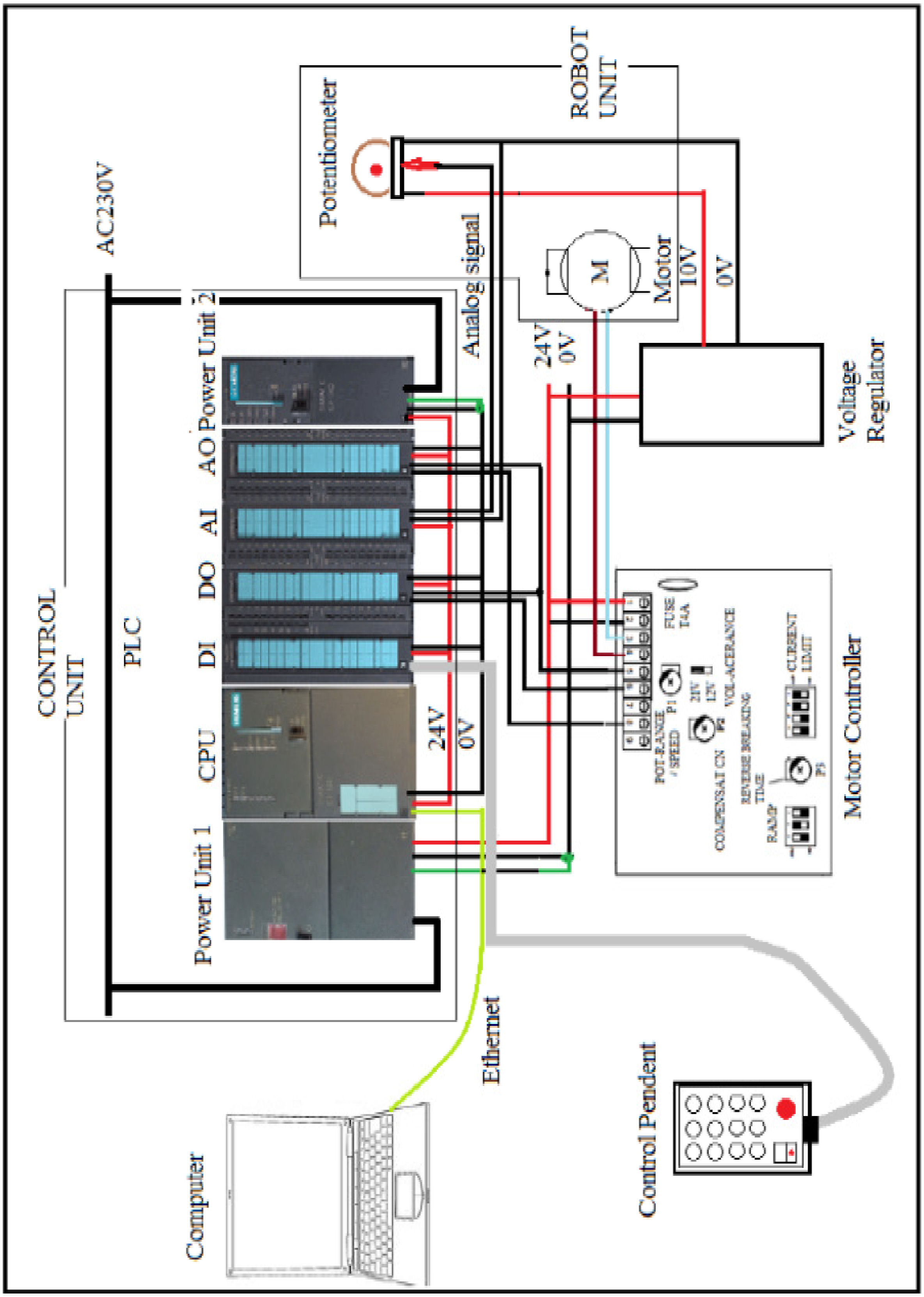


Figure 5.1 Layout of all the connecting Components

5.1 Inputs

There are two types of input modules used in the PLC; the analog modules and the digital modules. The analog inputs are from the potentiometers which are used for reading the angular value of the robot's axis and the digital inputs are from the control pendent. The control pendent contains 12 pushbuttons which are used for controlling the direction of motor in every axis. In addition to this an emergency switch and an indicator light are used in the box.

5.1.1 Control Pendent

All the inputs from the control pendant are digital inputs. Robotics axis movements are controlled using control panel, table 5.1.1 below shows some details about these motions.

Table 5.1.1

Control Pendent		PLC unit Location	Description
Name		Type	
Btn_1	Pushbutton	SM 321; DI 16 x 24 VDC	Push button to control the +ve movement of axis 1
Btn_2	Pushbutton	SM 321; DI 16 x 24 VDC	Push button to control the -ve movement of axis 1
Btn_3	Pushbutton	SM 321; DI 16 x 24 VDC	Push button to control the +ve movement of axis 2
Btn_4	Pushbutton	SM 321; DI 16 x 24 VDC	Push button to control the -ve movement of axis 2

Btn_5	Pushbutton	SM 321; DI 16 x 24 VDC	Push button to control the +ve movement of axis 3
Btn_6	Pushbutton	SM 321; DI 16 x 24 VDC	Push button to control the -ve movement of axis 3
Btn_7	Pushbutton	SM 321; DI 16 x 24 VDC	Push button to control the +ve movement of axis 4
Btn_8	Pushbutton	SM 321; DI 16 x 24 VDC	Push button to control the -ve movement of axis 4
Btn_9	Pushbutton	SM 321; DI 16 x 24 VDC	Push button to control the +ve movement of axis 5
Btn_10	Pushbutton	SM 321; DI 16 x 24 VDC	Push button to control the -ve movement of axis 5
Btn_11	Pushbutton	SM 321; DI 16 x 24 VDC	Push button to control the +ve movement of axis 6
Btn_12	Pushbutton	SM 321; DI 16 x 24 VDC	Push button to control the -ve movement of axis 6
Eme_0	Emergency	SM 321; DI 16 x	When

	Switch	24 VDC	emergency switch is pressed, one signal is sent to PLC to know the condition of emergency

5.2 Outputs

The output signals are used to control the axis of the arm. There are no other extra outputs to be controlled by the PLC. To control a single axis; an analog and a digital output are used from the PLC. Table 5.2.1 shows the axis movements while using control pendant.

Table 5.2.1

Name	PLC Unit	Description
Axi1_AO	SM 322; AO 4x 12 Bit;	Use for controlling the speed of the motor axis 1
Axi1_DO	SM 322; DO16 xDC 24 V/ 0.5 A	Use for changing the direction of the motor 1
Axi2_AO	SM 322; AO 4x 12 Bit;	Used for controlling the speed of the motor axis 2
Axi2_DO	SM 322; DO16 xDC 24 V/ 0.5 A	Use for changing the direction of the motor 2
Axi3_AO	SM 322; AO 4x 12 Bit;	Used for controlling the speed of the motor axis 3
Axi3_DO	SM 322; DO16 xDC 24 V/ 0.5 A	Use for changing the direction of the motor 3
Axi4_AO	SM 322; AO 4x 12 Bit;	Used for controlling the

		speed of the motor axis 4
Axi4_DO	SM 322; DO16 xDC 24 V/ 0.5 A	Use for changing the direction of the motor 4
Axi5_AO	SM 322; AO 4x 12 Bit;	Used for controlling the speed of the motor axis 5
Axi5_DO	SM 322; DO16 xDC 24 V/ 0.5 A	Use for changing the direction of the motor 5
Axi6_AO	SM 322; AO 4x 12 Bit;	Used for controlling the speed of the motor axis 6
Axi6_DO	SM 322; DO16 xDC 24 V/ 0.5 A	Use for changing the direction of the motor

6. Real Components

The components requirement is set according to the need of this thesis. In this part, the basic requirements are a control system design and a gripper design function. Both of them have completely deferent requirements which consist of the physical components and their features. On the basis of their features, the selection is done for these components which meet the required criteria. For each component, a short introduction and products specification is given.

6.1 PLC Components

The comparison among Phoenix contacts PLCs and Siemens PLCs shows that Siemens PLCs best suit for this application. The Siemens PLC components are readily available and it has its complete hardware and software system accessible to the Saimaa Laboratory. For this application, SIMATIC S7-300 PLC is considered the best. The different components of the S-300 PLC are:
CPUs

- Signal modules
- Function modules
- Communication

- Power Supply
- HMI (Human Machine Interface)
- Software

6.1.1 Central Processing Unit (CPU)

In the Siemens, CPUs and signal modules are designed as separate units. In other control system hardwares like Phoenix Contacts and FESTO, embedded CPUs and I/O units are used. Figure 6.1.1 below shows the typical CPU 315-2 PN/DP. In typical small PLC systems the CPU unit includes a number of input and output signal terminals, but in S7 300, the input and output terminal unit needs to be ordered separately.

Figure 6.1.1 CPU 315-2 PN/DP ***(Siemens AG manual 2010)***

Features

- The CPU with mid-range program memory and quality frame works.
- High processing power in binary and floating-point arithmetic
- Used as central controller in production lines with central and distributed I/O
- Component Based Automation (CBA) or PROFINET
- Combined MPI/PROFIBUS DP master/slave interface

- Isochronous mode on PROFIBUS. *(Siemens AG manual 2010)*

PROFIBUS is an electrical connector for linking control units to the automation module. It has a single multi-drop cable for connecting each sensor and actuator.
MPI (multipoint interface) PC adaptor is used for connecting the PC to the PLC. There are other types of connectors like the MPI driver which allowed connecting more than one master device on the network.

6.1.2 Signal Module

The analog and digital signal modules are the basic types of I/O units used in Siemens. But there are many varieties of these signal modules having larger to smaller number of inputs and outputs and bit capacity. There are four types of signal modules used in the application and all of them are listed below with features.

a). Analog output module (SM 332; AO 4 x 12 Bit)
Features:

- 4 outputs in one group
- The output can be selected by individual channel

- Voltage output
- Current output

- Resolution 12 bits
- Programmable diagnostics and diagnostic interrupt
- Electrically isolated to backplane bus interface and load voltage

(Siemens AG manual 2010)

b). Analog input module SM 331; AI 8 x 12 bit ;(6ES7331-7KF02-0AB0)
Features

- Resistance
- Temperature
- Programmable resolution at each channel group (15 bits + sign)
- Any measuring range per channel group
- Programmable diagnostics and diagnostic interrupt
- Programmable limit value monitoring for 8 channels
- High-speed update of the measured values at up to 4 channels

- Electrical isolation to the CPU
  (Siemens AG manual 2010)

c). Digital input module SM 321; DI 16 x DC 24 V High Speed;
(6ES7321-1BH10-0AA0).
Features

- 16 inputs, electrically isolated in groups of 16
- Rated input voltage 24 VDC
- Suitable for switches and 2- /3-/4-wire proximity switches (BEROs)
- Supports isochronous mode
  (Siemens AG manual 2010)
  d. Digital output module SM 322; DO 8 x DC 24 V/2 A;
  (6ES7322-1BF01-0AA0)

Features

- 8 outputs, electrically isolated in groups of 4
- Output current 2 A
- Rated load voltage 24 VDC
- Suitable for solenoid valves, DC contactors and signal lamps

(Siemens AG manual 2010)

6.1.3 Power Supply Unit

There are two types of power supply units from Siemens used for this application; PS 307; 5 A and PS 307; 2 A. The motor controllers are used for driving the motors. The starting current for the motor is about 3 amperes and the nominal motor current is about 1 ampere. So, the motor controller takes a larger amount of power than the PLC units. So, the power unit (307; 5A) is connected to Motor Controller and the Power Unit (PS 307; 2A) is connected for PLC units.

a) Power supply module PS 307; 2 A; (6ES7307-1BA01-0AA0). Figure 6.1.3 below shows a typical power supply module with a small description of components.

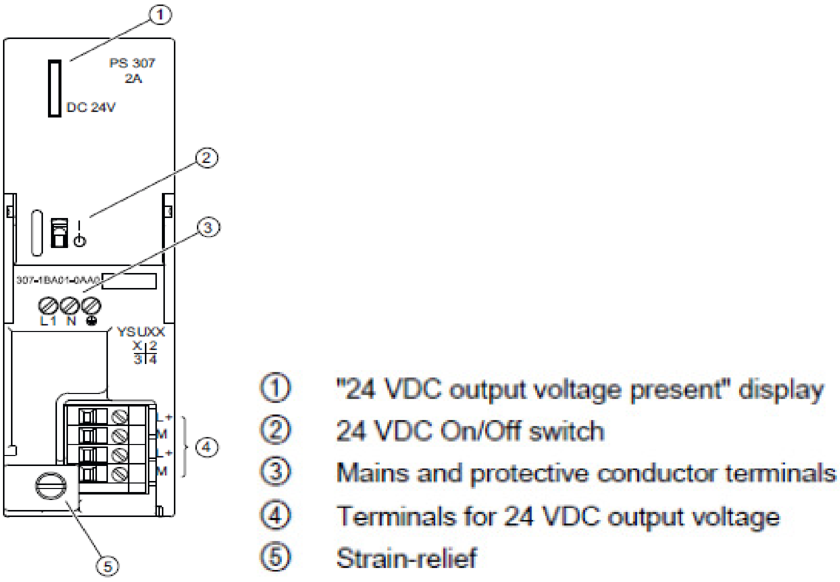


Figure 6.1.3 Power Supply, 2A

6.2 Potentiometer

The potentiometer used for measuring the joint angle of robot arm is Liner taper-E: 64-258-47. Figure 6.2.1 below shows the potentiometer used in the joint.

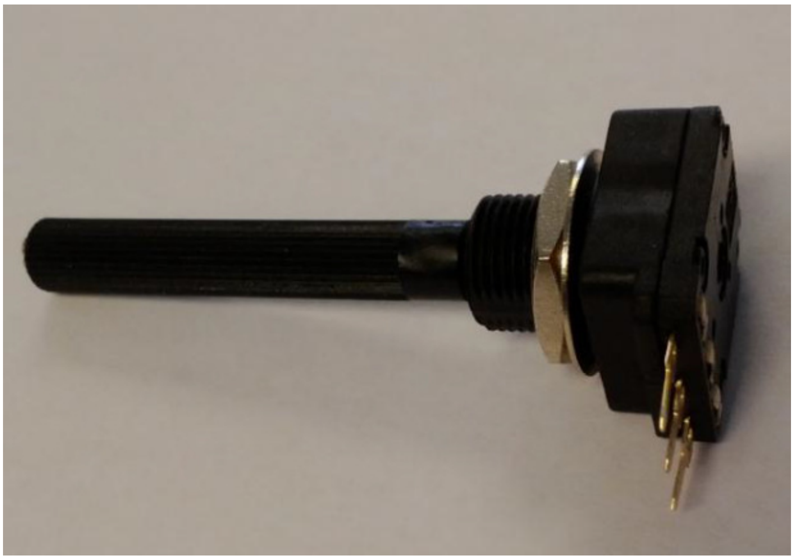


Figure 6.2.1 Potentiometer used in the joint

Features:

- Carbon resistive element
- Dust proof enclosure
- Polyester substrate

- Modular gang type (up to 4)
- Self extinguishable material UL 94-V0

Mechanical Specification

- Mechanical rotation angle: 300°±5°
- Electrical rotation angle: 280°±20°
- Max. torque nut (binding out): < 80 Ncm. (112 in-oz)
- Torque: 0.5 to 1.5 Ncm.

Electrical Specification

- Resistance range vaule: 0Ω ≤ Rn ≤ 10KΩ
- Tolerance: ±20 Ω
- Operating temperature:25℃+70℃

6.3 DC Motor Controller

The DC motor controller chosen for this application is *EM-101-BI MOTOR CONTROLLER 24V 4A 4-QUAD*. This motor controller uses analog ±10 voltage as an input signal for controlling the speed and direction of the motor. The output power range is 5...80W and due to high pulse width modulation control (PWM) the unit has high efficiency, low heat losses and provides a high starting torque. Loading of the motor can be compensated with inbuilt RI-adjustment. Figure 6.3.1 below shows the DC Motor Controller. There is a variety of braking options available in this device. For most effective braking "reverse braking" mode can be used. *(Electromen Oy, n.d.)*

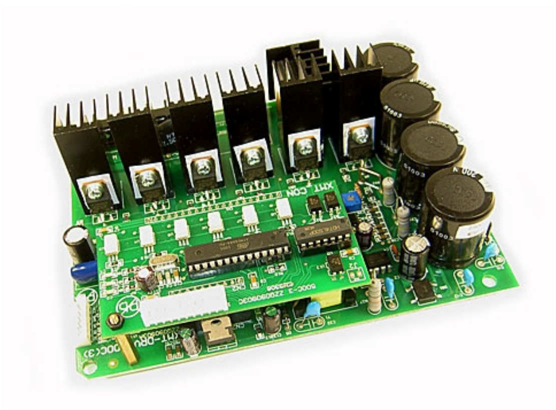


Figure 6.3.1 DC Motor Controller

FEATURES:

- 4-quardant
- Protection with self recovering fuse
- Settable current limit
- Settable acceleration/brake ramp
- Load compensation
- Speed control ±10V(±5V)
- Positive Control logic
- Direction and speed controlled with analog voltage signal and digital voltage signal.
- (U-cont. Forward 0…1V
- Backward 4…30V)

According to the motor's power, the DIP-switches can be adjusted to limit the output current. The adjustment can be made by the right arrangement of the DIP-switches. The configuration of the DIP-switches is shown in Figure 6.3.2 below. DIP-switches for controlling the current.

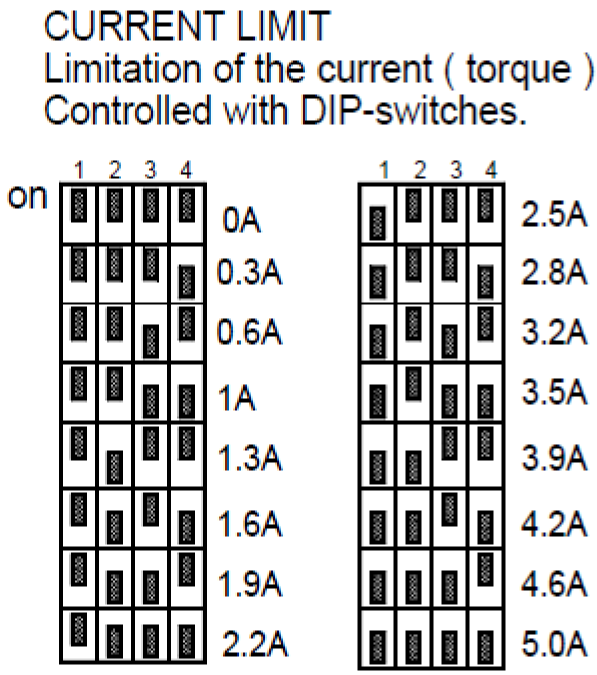


Figure 6.3.2 DIP-switches for controlling the current

The EI-101-BI DC motor controller has the following 6 different options for controlling the speed and direction of motor. According to the need of the application, any of these options can be selected. Figure 6.3.3 below shows the EI- connection example.

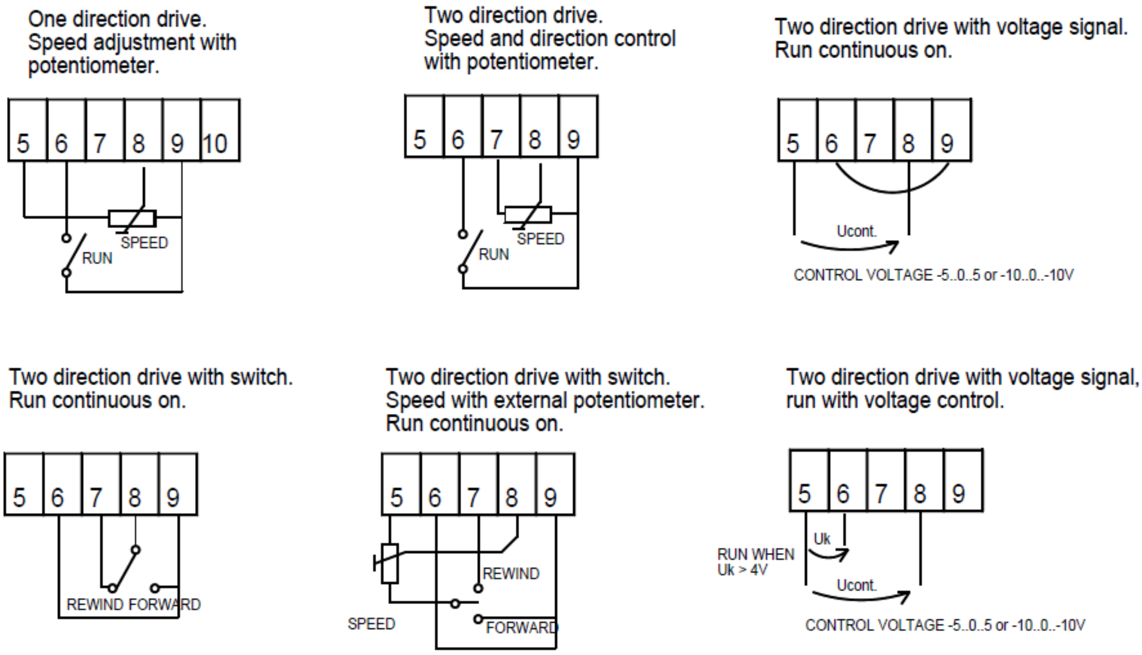


Figure 6.3.3 EI- connection example

6.4 Voltage Regulator

Figure 6.4.1 below shows the Voltage Regulator Circuit diagram. For each potentiometer, a constant voltage supply is necessary. Due to this reason, a voltage regulator is used. The voltage regulator used for the application is HB7809. It has the constant output voltage of 9V. The voltage range for analog signal module can be set according to the condition. For this purpose, the analog signal processing range can be set as 0- 10V. The circuit diagram for the voltage regulator is shown below.

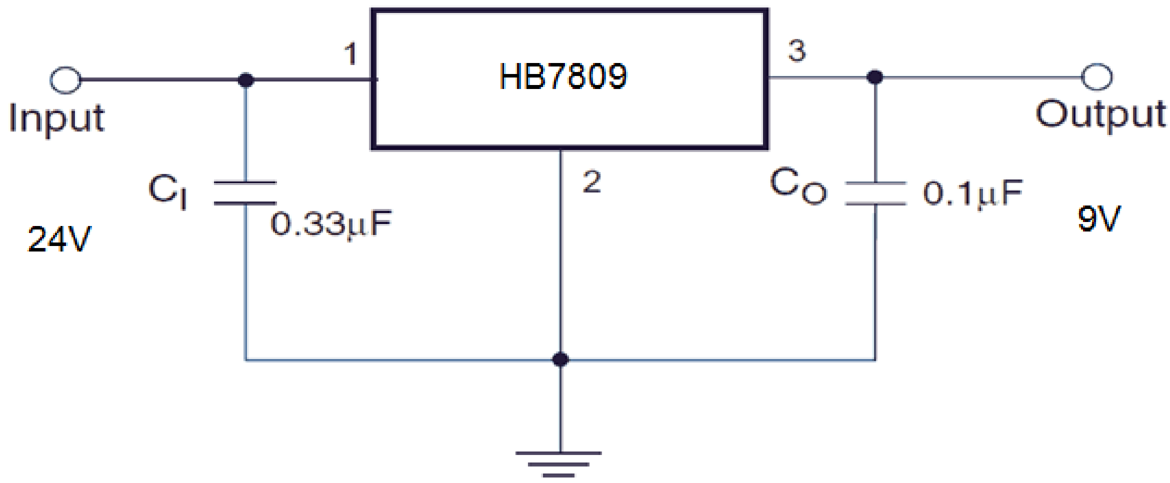


Figure 6.4.1 Voltage Regulator Circuit diagram

(https://www.google.com/search?hl=fi&site=imghp&tbm=isch&source=hp&biw=1280&bih=856&q=voltage+regulator&oq=voltage+re&gs_l=img.1.0.0l2j0i30l8.1672.3778.0.5157.10.8.0.2.2.0.71.531.8.8.0.msedr...0...1ac.1.64.img..0.10.552.Z2uKKCiaFRU)

The real construction of the voltage regulator board is constructed using the above wiring diagram which is shown in the Figure 6.4.2 below.

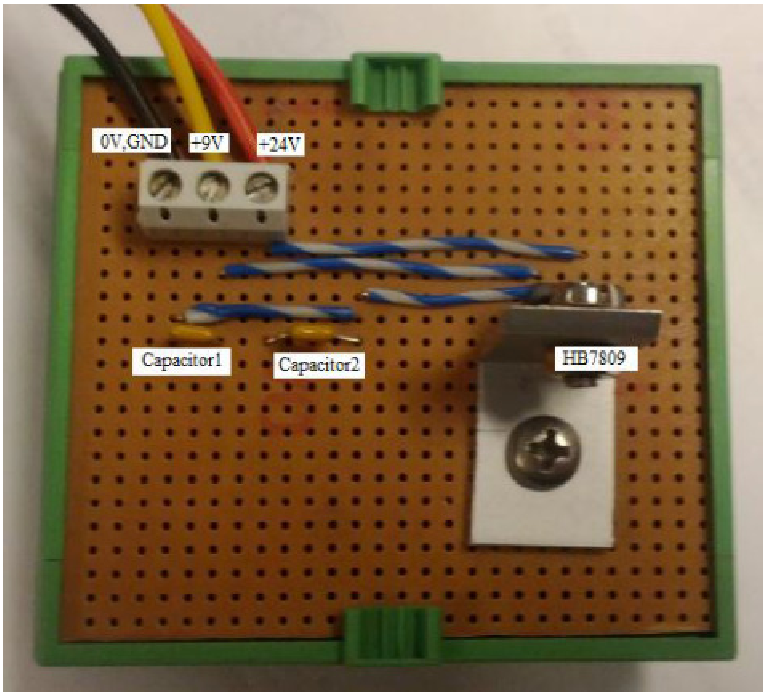


Figure 6.4.2 Voltage Regulator Board

6.5 DC Motor

There are two types of gear motors used in the Robotic Arm i.e. RH158.24.200 and E192.24.200. Figures 6.5.1 and 6.5.2 below show the gear motor E192.24.200 is used in only one axis whereas the motor type RH 158.24.200 is used in the remaining five axes.

Figure 6.5.1 Motor (RH158.24.200)

Features

1. VDR interference suppression on the collector
2. Direction of the rotation depends on the polarity
3. Maximum radial shaft load: 50N
4. Maximum axial shaft load: 10N
5. Temperature range: -20℃/60℃
6. Weight: Approx. 190 g

Technical Details

Nominal voltage:24V

Gear ratio: 198,5

Maximum torque: 100 Ncm

Speed (No Load) : 33 rmp

Speed (at Max torque) : 23 rmp

(micromotors, n.d..)

Figure 6.5.2 Motor (E192.24.200)

Features

1. VDR interference suppression on the collector
2. Direction of the rotation depends on the polarity
3. Maximum radial shaft load: 200N
4. Minimum axial shaft load: 100N
5. Temperature range: -20℃/60℃
6. Weight: Approx. 385/480 g

Technical Details

Nominal voltage 24V

Gear ratio: 125

Maximum torque: 300 Ncm

Speed (No Load) : 33 rmp

Speed (at Max torque) : 26 rmp

6.6 Linear Actuator

Linear Actuator is designed in such a way that it can transmit an object linearly with the help of a screw system as shown in the figure below. The threaded axis rotates by the help of motor and due to the screw on the axis, it slides back and forth. With the help of a linear actuator, a mechanical system can be designed for gripping objects. Figure 6.6.1 below shows the 3D Model of Linear Actuator. The light weight and electrically controlled drive will be the best choice because it can be easily controllable and does not need additional pneumatic power and pneumatic components.

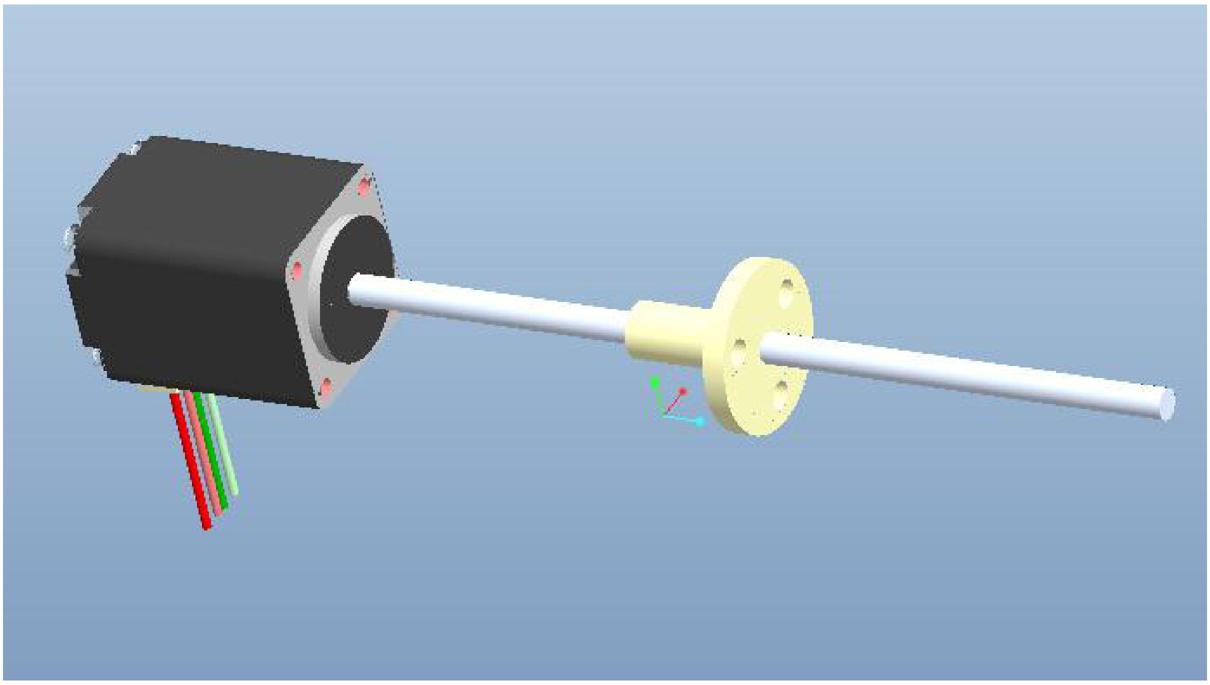


Figure 6.6.1 3D Model of Linear Actuator (Haydon 21000 Series)

6.7 Control Pendent

The control box is necessary to control the robotic arm. There is an operational switch like ON/OFF and an emergency switch for the basic control. To control the movement of the arms, there are 12 push buttons. Figure 6.7.1 below shows the control pendent for controlling the movements of the Robotic Arm. For a single axis, the clockwise and anti-clockwise rotations are controlled by two switches. A shielded wire is used for carrying the signal.

Figure 6.7.1 Control pendent for controlling the movements of the Robotic Arm

7. Circuit and Wiring Design

7.1 Circuit Board

The real circuit was designed on a wooden board as shown in the figure below. All the control system units and Robotic Arm were fixed in the same wooden board. The wiring connection between each component was done in a systematic manner. There were C-rails for fixing the PLC components and motor controller and the connecting wires were fixed in the isolated tubes. Figures 7.1.1 and 7.1.2 below show the wiring connections between PLC and motor.

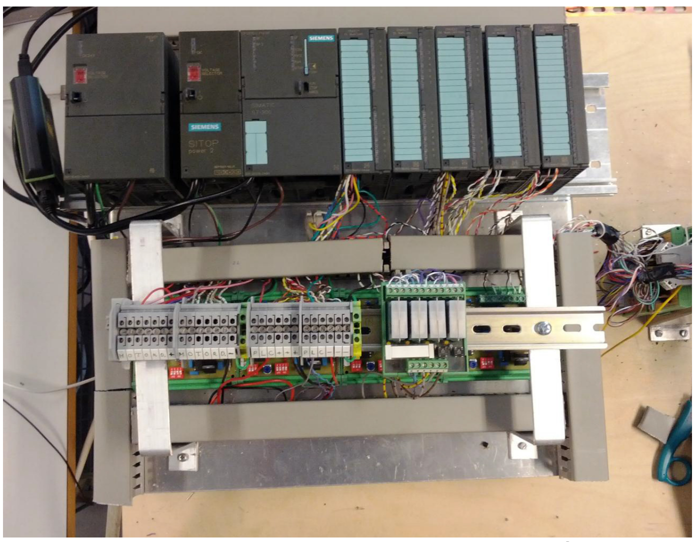


Figure 7.1.1 Wiring connections between PLC and motor controller.

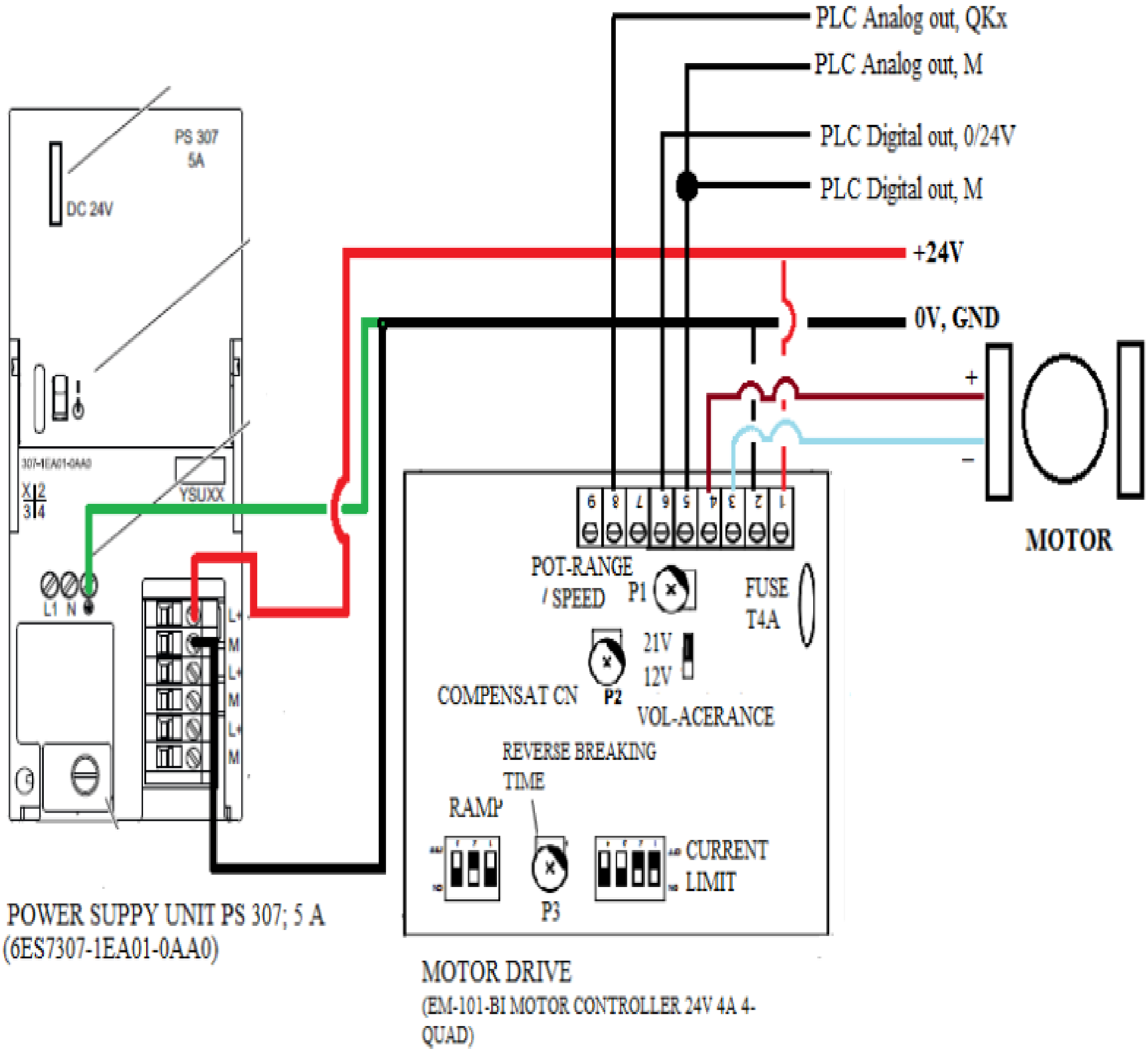


Figure 7.1.2 Wiring diagram

The speed and direction of the motor is controlled using the combination of analog output signal and digital output. The analog output is used for controlling the speed of and direction of the motor and the digital signal is used for enabling the Motor Controller. The digital output acts like an ON/OFF switch for a motor. The Analog output module SM 332; AO 4 x 12 Bit; has the different options in output voltages; i.e. ± 10 V, 0V to 10V and 1V to 5V. The motor drives can be controlled with ± 5V or ± 10V. Due to this reason, ± 10 V voltage options can be selected for this application.

The analog output module has only 4 options, all the six motors cannot be driven. To solve this problem, the remaining two motors will be controlled by digital signals. The digital signal can drive the motor in two directions but it cannot control the speed of motors. The speed of the motor will be constant in every case. The two motors which are controlled by the digital signals are at the end of the arm and these motors can not much load compared to other motors.

The wiring connection between PLC and motor controller is shown in Figure 7.1.4 below.

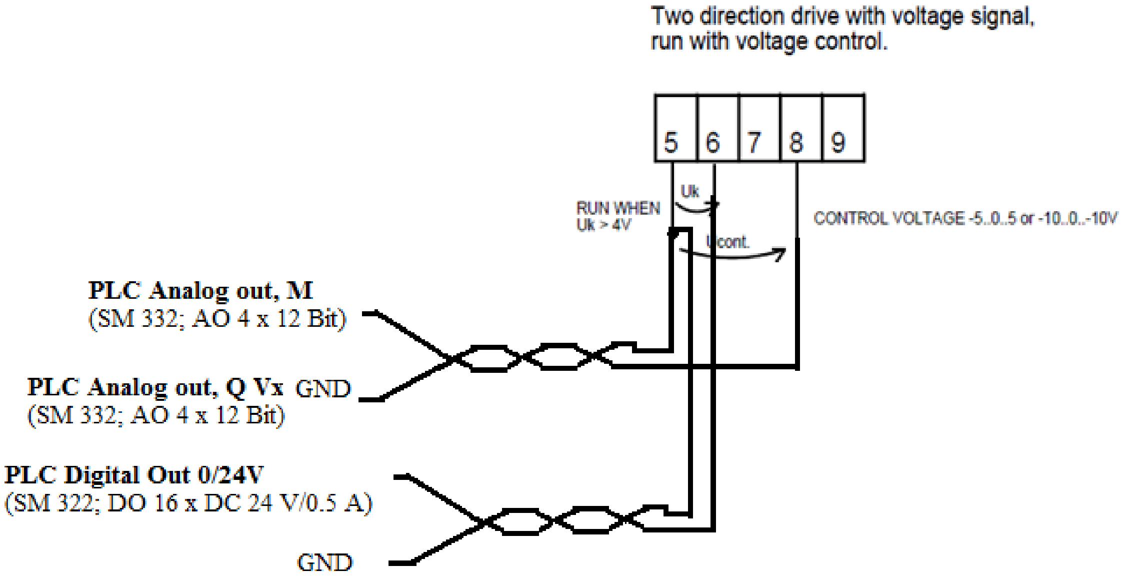


Figure 7.1.4 Motor Controller wiring connection

7.2 Bridge Board

To make a connection bridge between control units and Robotic Arm, there is a small circuit board designed. This circuit board connects all the analog inputs from potentiometer to the PLC and power line from motor controller to axis motor. This board is designed in such a way that, all the connection wires can be easily plugged in and plugged out for the convenient wiring. The circuit diagram is shown below in Figure 7.2.1.

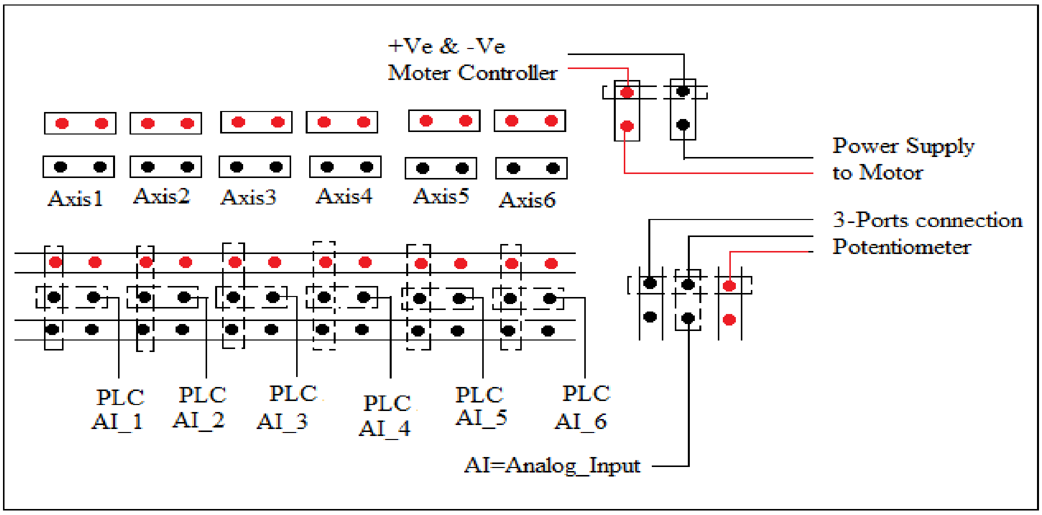


Figure 7.2.1 Bridge board Circuit Diagram

The real construction of the bridge board is done using the wiring principle of the above diagram. It is shown in Figure 7.2.2 below.

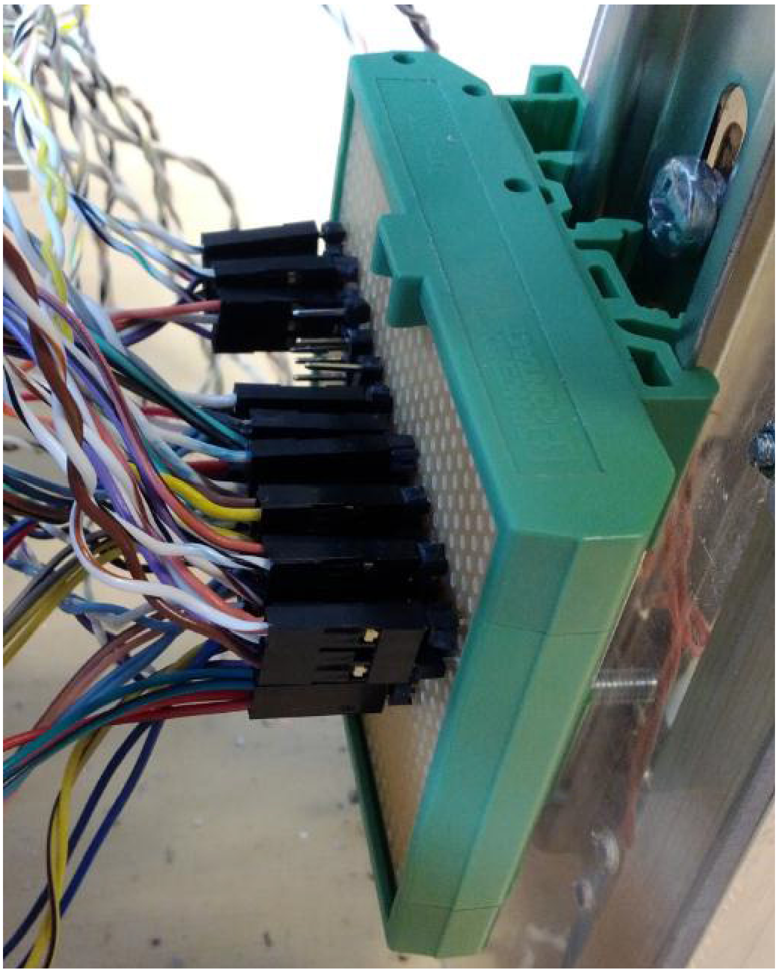


Figure 7.2.2 Bridge Circuit Board

7.3 Control Pendent Circuit

Control Pendent is designed with 12 push buttons for driving 6 motors in +ve and -ve direction. Figure 7.3.1 shows the wiring connection of the control pendent and signal module.

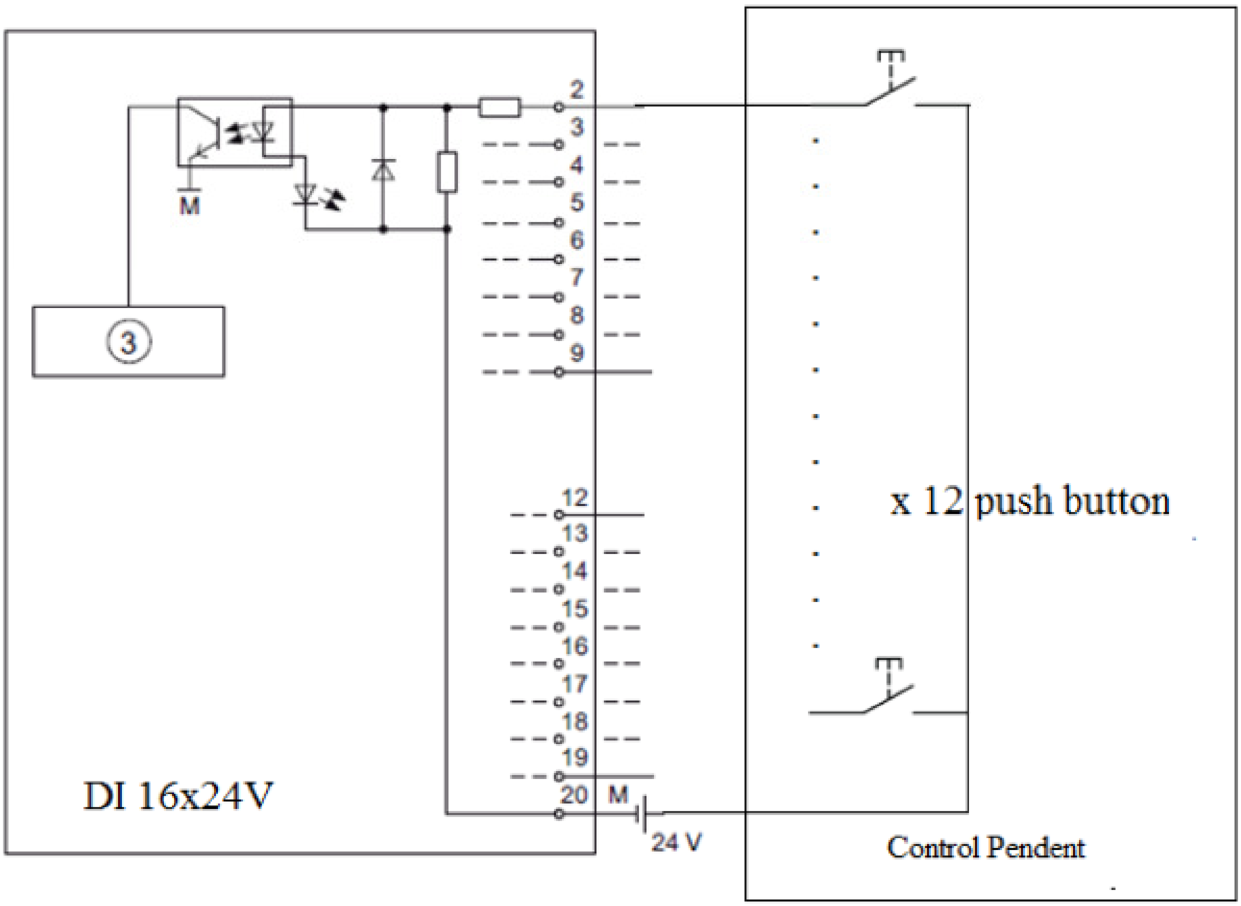


Figure 7.3.1 Wiring connection of the control pendent and signal module (DI 16x24V)

7.3.1 Control Pendant Motion Description

Table 7.3.1 below shows the elaboration of control pendant implementation, it shows how the different buttons can be used for different kinds of motions.

Table 7.3.1

<table>
<tr><th colspan="3">Control Pendent</th><th colspan="3">Wiring</th><th colspan="3">PLC</th><th colspan="3">Description</th></tr>
<tr><td colspan="2">Name</td><td colspan="2">I/O Type</td><td colspan="2">Color</td><td colspan="2">Type</td><td colspan="2">Unit</td><td colspan="2">Port number</td></tr>
</table>

Push button	Digital Input	Red	0.4mm2	DI 16x 24VDC	2	Driving +ve rotation of motor axis 1
Push button	Digital Input	Green	0.4mm2	DI 16x 24VDC	3	Driving +ve rotation of motor axis 1
Push button	Digital Input	yellow	0.4mm2	DI 16x 24VDC	4	Driving +ve rotation of motor axis 2
Push button	Digital Input	white	0.4mm2	DI 16x 24VDC	5	Driving -ve rotation of motor axis 2
Push button	Digital Input	Black	0.4mm2	DI 16x 24VDC	6	Driving +ve rotation of motor axis 3
Push button	Digital Input	Red	0.4mm2	DI 16x 24VDC	7	Driving -ve rotation of motor axis 3
Push button	Digital Input	Green	0.4mm2	DI 16x 24VDC	8	Driving +ve rotation

						of motor axis 4
Push button	Digital Input	yellow	0.4mm2	DI 16x 24VDC	9	Driving -ve rotation of motor axis 4
Push button	Digital Input	white	0.4mm2	DI 16x 24VDC	12	Driving +ve rotation of motor axis 5
Push button	Digital Input	Black	0.4mm2	DI 16x 24VDC	13	Driving -ve rotation of motor axis 5
Push button	Digital Input	Red	0.4mm2	DI 16x 24VDC	14	Driving +ve rotation of motor axis 6
Push button	Digital Input	Green	0.4mm2	DI 16x 24VDC	15	Driving -ve rotation of motor

8. Programming

8.1 Programming Tool

The programming tool used for the S-300 PLC model is TIA Portal V11 Sematic software. Totally integrated automation (TIA) is programming software from Siemens which is used for the industrial control system with a wide range of applications and features.

With STEP 7 Basic V11, the following functions can be utilized for automating a system

- Configuring and parameterizing the hardware
- Specifying the communication
- Programming
- Test, commissioning and service with the start/diagnostic functions
- Documentation
- Generating visual displays for the SIMATIC basic panels

8.2 Defining Input and Output Variables

A list of input and output variables in each category is declared using a particular keyword with particular address. Within each list, each variable identifier is followed by its data type which may be elementary or derived. The variables used within local variables are declared using the keyword “VAR”. The picture shown below is the window of the PLC tags, defining the variables.

This category of variable allows PLC memory locations to be referenced directly, i.e. without using an identifier. All identities of directly represented variables start with a “%” character. This is followed by a one or two letter code that defines whether the memory location is associated with inputs, outputs or internal memory, and the type of memory organization, e.g. as bits bytes or words. PLC memory is considered to be organized into three major regions: (I) input locations for receiving values from channels such as digital input and analogue modules, (Q) output locations for values to be sent on to output channels, and (M) internal memory locations for holding intermediates values. (Lewis 1998, 69)

Table 8.2.1 below shows the different symbols used for PLC programming.

Table 8.2.1

First letter code	Interpretation
I	Input memeory location
Q	Output memory location
M	Internal memory

Second Letter code	Interpretation
X	Bit
B	Bytes (8 bits)
W	Word (16 bits)
D	Double word (32 bits)

There are digital and analog input variables which need to be defined for the programming. On the basis of the signal module address area and the types of data, these input variables are defined. The digital input (DI) is defined to be the data type BOOL and address starting with address %I0.0. The digital signal modules DI16 ×24 VDC_1 have the input address area of 0...1. So, for the signal from control pendent, all the input is defined as BOOL variables and assigned with this address.

8.2.1 Input Variables

These input variables are defined according to the software's need. The hardware configuration in the software gives the data type limitation and the address area for the signal. In this case, the digital modules are used for receiving the ON/OFF signal from the control pendent, whereas the analog input modules receive the signal from the potentiometer. The address of the first analog input would be in this case %IW 320, that of the second analog input %IW322 and so on. Table 8.2.1 below shows the different symbols for inputs of PLC.

Table 8.2.1

Input Symbol	Data Type	Address	Comments
Btn_1	BOOL	%I0.0	Push button in control pendent to control +Ve axis 1
Btn_2	BOOL	%I0.1	Push button in control pendent to control -Ve axis 1
Btn_3	BOOL	%I0.2	Push button in control pendent

			to control +Ve axis 2
Btn_4	BOOL	%I0.3	Push button in control pendent to control -Ve axis 2
Btn_5	BOOL	%I0.4	Push button in control pendent to control +Ve axis 3
Btn_6	BOOL	%I0.5	Push button in control pendent to control -Ve axis 3
Btn_7	BOOL	%I0.6	Push button in control pendent to control +Ve axis 4
Btn_8	BOOL	%I0.7	Push button in control pendent to control -Ve axis 4
Btn_9	BOOL	%I1.0	Push button in control pendent to control +Ve axis 5
Btn_10	BOOL	%I1.1	Push button in control pendent to control -Ve axis 5
Btn_11	BOOL	%I1.2	Push button in control pendent to control +Ve

			axis 6
Btn_12	BOOL	%I1.3	Push button in control pendent to control -Ve axis 6
A_in1	INT	%IW304	Analog input signal of axis 1
A_in2	INT	%IW306	Analog input signal of axis 2
A_in3	INT	%IW308	Analog input signal of axis 3
A_in4	INT	%IW310	Analog input signal of axis 4
A_in5	INT	%IW312	Analog input signal of axis 5

8.2.2 Output Variables

For defining the output variables, there are address areas set in the software. According to the need of output for controlling the motor, two output variable types BOOL and INT are defined and used for the programming. Table 8.2.2 defines the variables in the PLC output tags lists.

Table 8.2.2

Output Symbol	Data Type	Address	Descriptions
D_Out1	BOOL	%Q8.0	Controlling the direction of rotation of motor axis 1
D_Out2	BOOL	%Q8.1	Controlling the direction of rotation of motor axis 2
D_Out3	BOOL	%Q8.2	Controlling the

			direction of rotation of motor axis 3
D_Out4	BOOL	%Q8.3	Controlling the direction of rotation of motor axis 4
D_Out5	BOOL	%Q8.4	Controlling the +ve rotation of axis 5
D_Out6	BOOL	%Q8.5	Controlling the -ve rotation of axis 5
D_Out7	BOOL	%Q8.6	Controlling the +ve rotation of axis 6
D_Out8	BOOL	%Q8.7	Controlling the -ve rotation of axis 6
A_in1	INT	%QW320	Controlling the speed of the motor axis 1
A_in2	INT	%QW322	Controlling the speed of the motor axis 2
A_in3	INT	%QW324	Controlling the speed of the motor axis 3
A_in4	INT	%QW326	Controlling the speed of the motor

8.3 Analog Signal Processing

The binary signal that can assume only the two signal states “voltage available +24V” and “voltage unavailable 0V”, analog signal within a certain range are able to assume any number of values. A typical example for an analog signal is a potentiometer. Depending on the position of potentiometer, the signal value has changes.

Examples of analog variable in control engineering:
Temperature -50 … + 150℃
Flow rate 0 … 200l/min
Speed 500 … 1500 U/min
Etc.

If analog variables are processed with a PLC, the voltage, current or resistance value that was entered has to be converted to digital information. This conversion is called analog-digital conversion (A/D conversion). This means, for example: the voltage value of 3.65V is stored in a series of binary digits as information. The more binary digits are used for digital representation, the higher is the resolution. If, for example, only 1 bit were available for the voltage range 0 ... +10V, information could be provided only as to whether the measured voltage was within the range of +5V ... +10V. With 2 bits, however, the range can be subdivided into 4 individual ranges; i.e. 0 ... 2.5/2.5 ... 5/5 ... 7.5/7.5 ... 10V. In control engineering, commercial A/D converters convert with 8 or 11 bits, whereby 8 bits provide for 256 individual ranges, and 11 bits a resolution of 2048 individual ranges. (Analog value processing, 2010)
The data types ’INT’ und ’REAL’ are very important in analog value processing since entered analog values are present as integers in the format ’INT’. For exact further processing, only floating point numbers ’REAL’ can be used because of the rounding error at ’INT’.

The analog signal from the potentiometer is assigned with the physical angular value. This conversion of the angular value is done with simple mathematics. The range of maximum and minimum input voltage is assigned with the optimum rotation angle of the potentiometer. The bit capacity of the analog modules defines the resolution of the signal. The INT value after conversion of the analog signal depends upon the bit capacity of the module. Figure 8.3.1 below shows the illustration of the conversion of angular value to the Int. value.

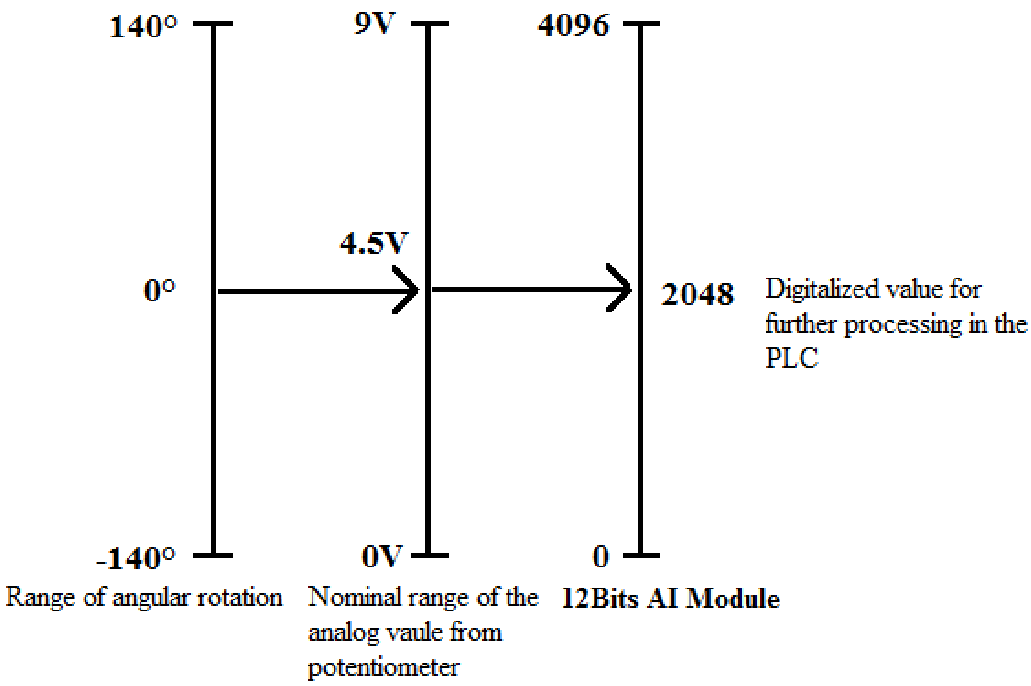


Figure 8.3.1 Diagram illustrate the conversion of angular value to the Int. value

The INT value for every axis is recorded using the online simulation. An axis is rotated manually, so that the maximum and minimum limits can be identified. There are errors in two of the axis (axis 3 and axis 5) due to the physical defects; maybe the potentiometers are broken. Due to this, limitation for the maximum and minimum rotation cannot be set in the program for these joints. Table 8.3.1 below shows the maximum and minumum values for axis rotation.

Table 8.3.1

Axis Number	Minimum	Maximum
1	5896	15336
2	3312	24544
3	-	-
4	3016	24864
5	-	-
6	1504	20416

The analog input modules and analog output modules must be set in the program such that it computes with the correct signal be set the programming. With the device configuration in the program, the measuring signal types and range can be set.

Table 1 Analog Input channel setting (AI8x12bits) (TIA Automation)

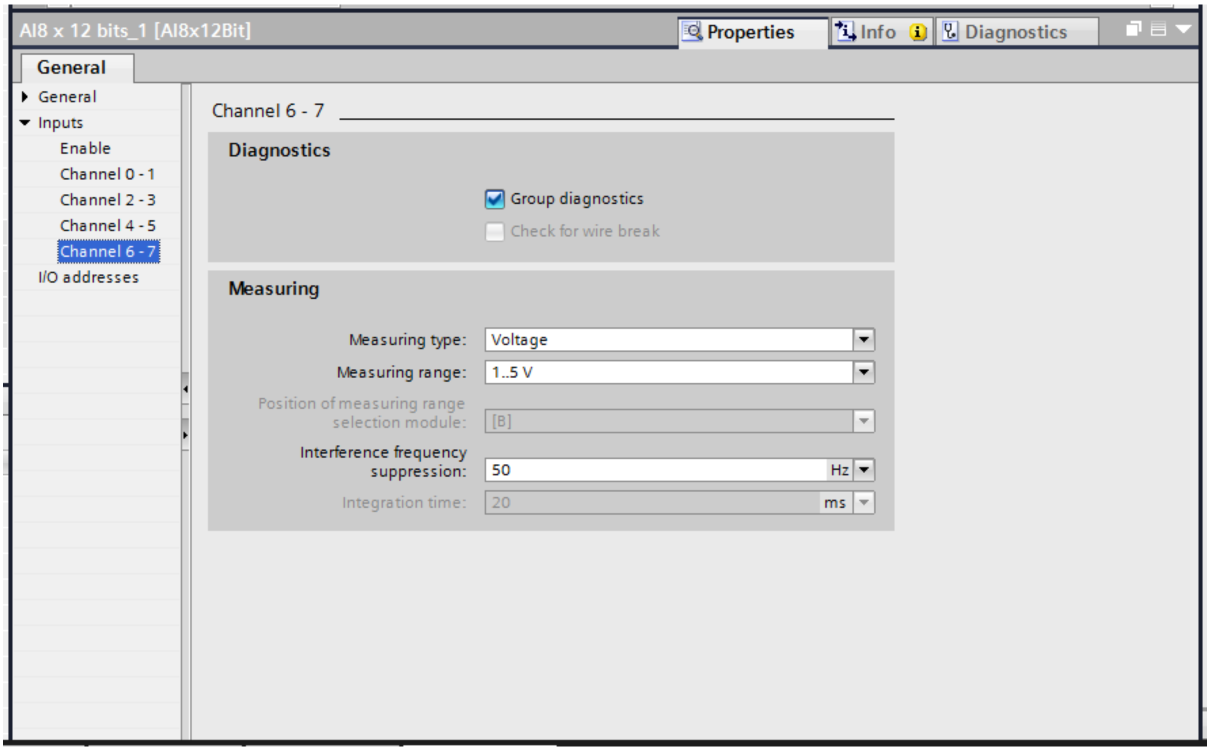
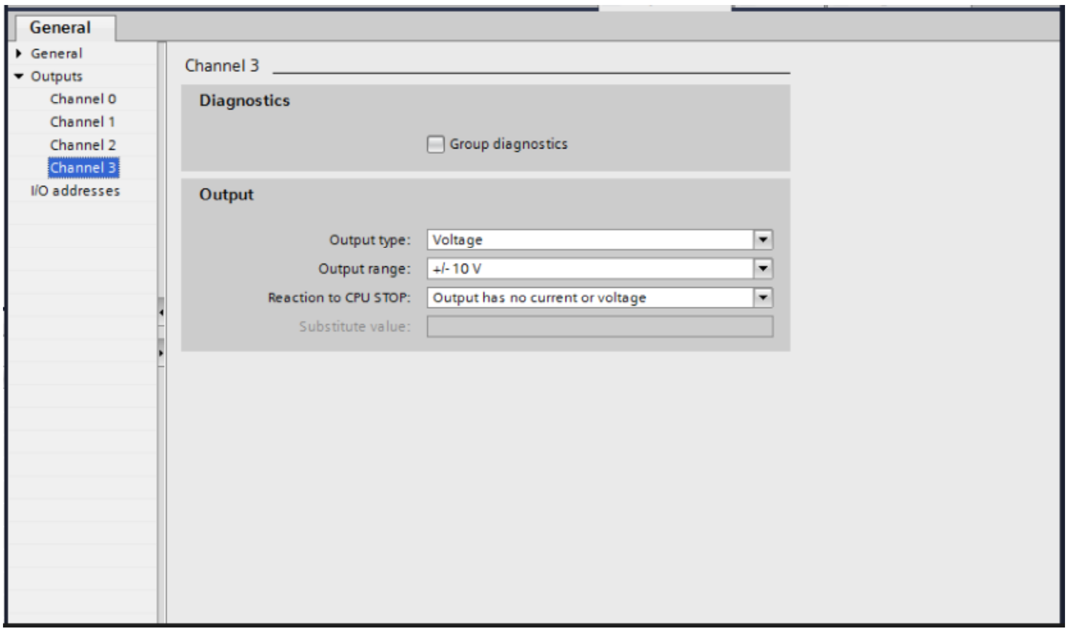


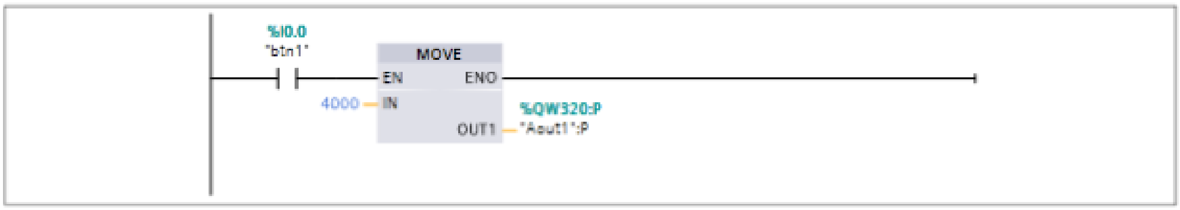
Table 2 for the analog output modules, the range of output is set to be ±10V. (TIA Automation)



8.4 Manual Control Modes

The programming is done for the manual control of the arm. The PLC is programmed in such a way that it can make the positive and negative movement for every axis. The 12 buttons of the control pendent are used to control 6 motors in two different directions. The speed of the motor can be simply controlled by the INT value for the analog output. The positive integer value helps to rotate the motor in positive direction whereas the negative INT value helps to rotate the motor in negative direction. The ladder logic program for controlling the direction and limiting the speed of the motor is shown below. Figure 8.4.1 below shows the network 1 of PLC programming.

Network 1:

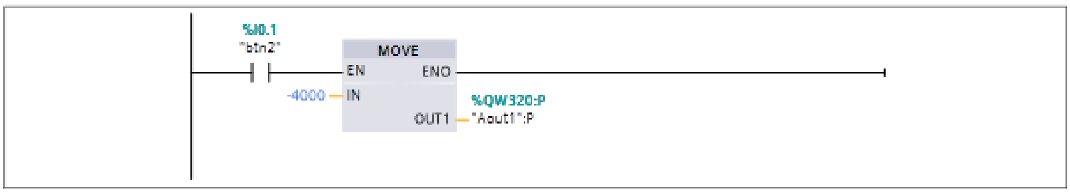


Symbol	Address	Type	Comment
"btn1"	%I0.0	Bool	
"Aout1":P	%QW320:P	Int	
4000	4000	Int	

Figure 8.4.1 PLC Programming network

In this program, the analog output value for driving the motor axis in positive direction is 4000. When button 1+ is pressed, axis 1 rotates in positive direction with the speed and direction given by the INT value of 4000 and to reverse the direction of the rotation of axis 1, button 2 is pressed which enables the analog output INT value of -4000. Figure 8.4.2 below shows the network 2 of PLC programming.

Network 2:

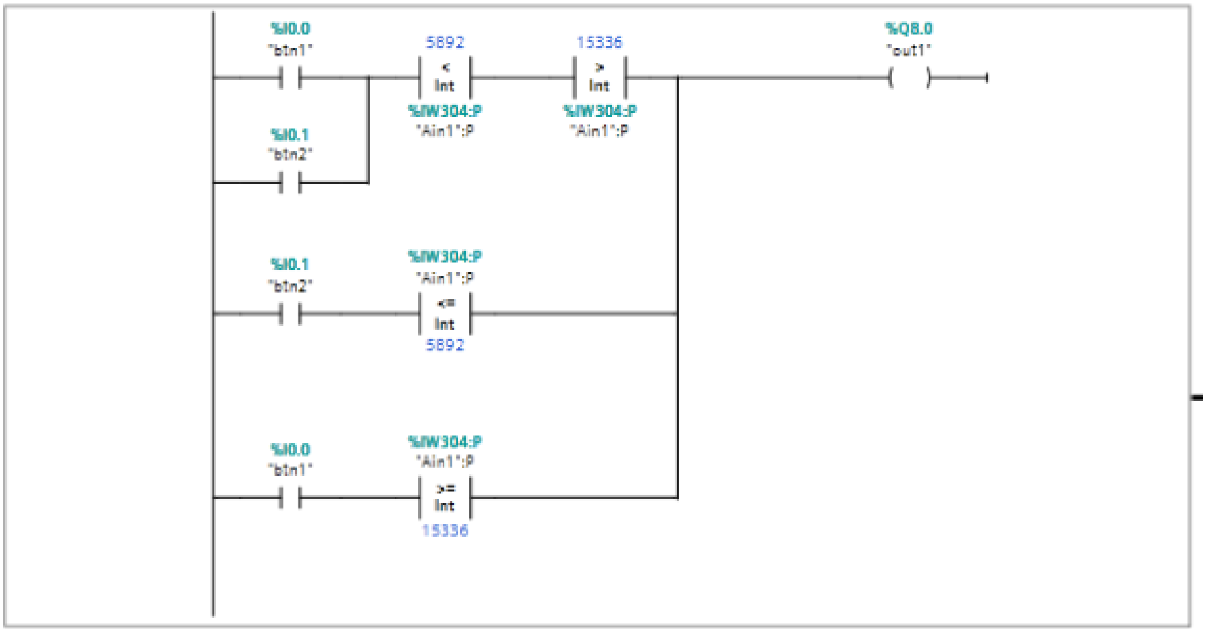


Symbol	Address	Type	Comment
"Aout1":P	%QW320:P	Int	
"btn2"	%I0.1	Bool	
-4000	-4000	Int	

Figure 8.4.2 PLC programming network

In a manual control system, the limit of the rotation of every axis is controlled by the analog input value from the potentiometer. The reading from the potentiometer value is taken in the PLC program during the online simulation. The maximum and minimum values are recorded as the rotation limits in two direction and the maximum and minimum limits help to protect the motor from the collision. The program written for limiting the rotation angle is shown below. Figure 8.4.3 below shows the network 3 of PLC programming along with input symbols.

Network 3:



Symbol	Address	Type	Comment
"btn1"	%I0.0	Bool	
"out1"	%Q8.0	Bool	
"btn2"	%I0.1	Bool	
"Ain1":P	%IW304:P	Int	
5892	5892	Int	
15336	15336	Int	

Figure 8.4.3 PLC prgramming network

The first four axes have the speed control during rotation but the remaining two do not have the rotation speed control system in them. It is because, there are only 4 analog outputs available in this PLC which is used for four motor and the next two are driven by the direct relay. The relay drives the motor with full speed and it does not have any speed control. Actually, the motors driven by the relay are at the end of the arm, so it does not have much inertia and does not produce vibration problem.

The problem in using the relay is that, it does not have current protection circuit and there is always the risk of motor damage due to high current. But to test the programs arm performance during its operation, relay is used.

The positive and negative movement is controlled by the digital outputs. This digital output is connected to a relay which act like ON/OFF-switch for controlling the direction of the motor. Figure 8.4.4 below shows networks 13 and 14 of PLC programming along with output symbols.

Network 13:

Symbol	Address	Type	Comment
"btn9"	%I1.0	Bool	
"out5"	%Q9.0	Bool	

Network 14:

Network 14:

Symbol	Address	Type	Comment
"btn10"	%I1.1	Bool	
"out6"	%Q9.1	Bool	

Figure 8.4.4 PLC programming network

For controlling the rotation limit, where relay is used, the same type of program is used as above.

8.5 Automatic Movement

The programming for the automatic movement control system of the arm is done in such a way that it performs a sequence of task. The position and orientation of the arm can be determined by the INT value from the potentiometer, but the calculation is complex. The program is just the demonstration for controllable automatic movement of Robotic Arm. The program is written in such a way that, each axis has the set-reset (SR) program which continuously rotates the motor axis back and forth. The movement starts with the set button and stops immediately when the reset button is pressed. The program can limit the rotation of the axis before collision.

During the running modes, a single integer value (Int = 2000) cannot set or reset the program, because of the slow processing speed of the PLC, so a range of INT value (2000 < Int < 3000) is placed to control the SR circuit in the program.

Figure 8.5.1 below shows the ladder logic program for controlling the forward movement.

Network 1:

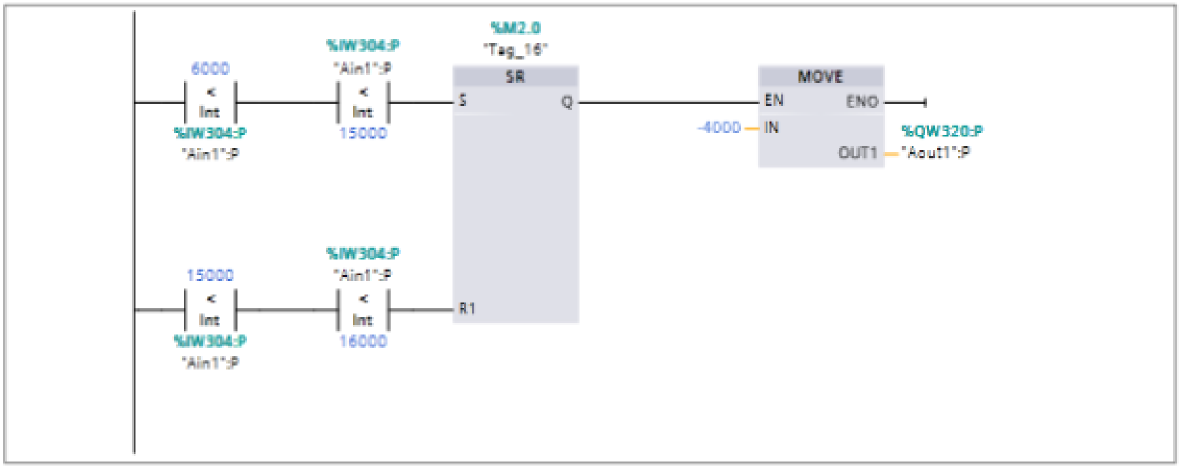


Figure 8.5.1 PLC programming to control Forward motion

Figure 8.5.2 below shows the ladder logic program for controlling the backward movement

Network 2:

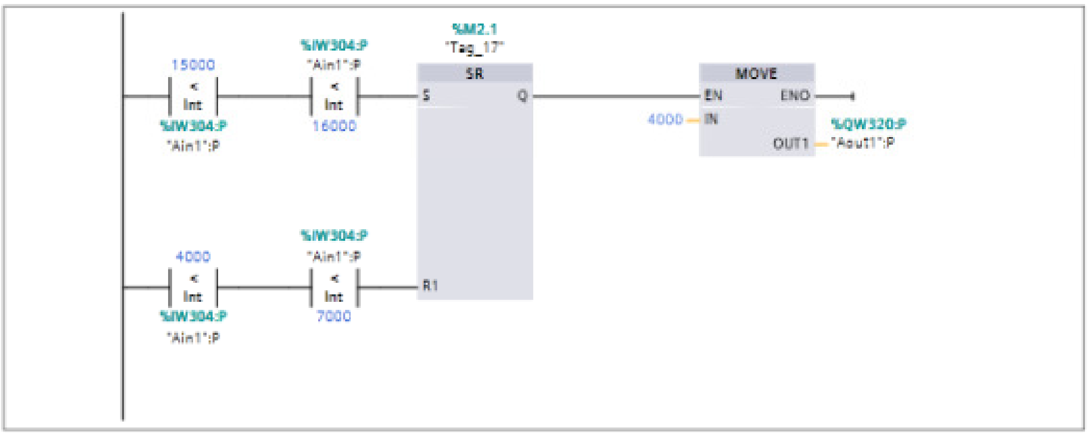


Figure 8.5.2 PLC programm network for backward motion

Figure 8.5.3 below shows the programme for output working as ON/OFF switch for controlling the motor.

Network 3:

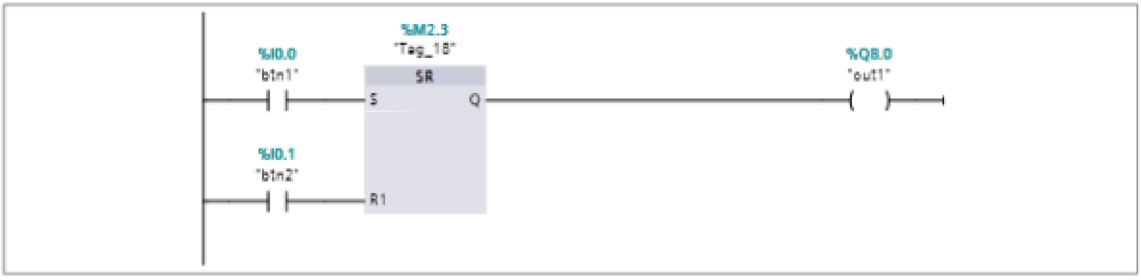


Figure 8.5.3 PLC programming network

9. Design of Gripper

This section includes the design and construction phase of the gripper. All the necessary design processes for a complete product are included in this part. As compared to real a design process in a real working life, this gripper design also includes all the essentials theoretical aspects of a product development.

9.1 Gripper Design

Figure 9.1.1 below shows the typical robotics gripper. The following pictures show the mechanical grippers for a robotic arm. All of these mechanical grippers use the linear actuator and linear actuator can be easily controlled by the DC motor. The main aim to use the DC motor in the gripper is to make all the functions controlled by electricity. Using an extra pneumatic or hydraulic system for a gripper adds more complication and expenses.

All the 3D modes of the grippers are designed using Pro E. and among all of this gripper, only one of these grippers is made finalized. Figure 9.1.1 below shows the typical robotics gripper.

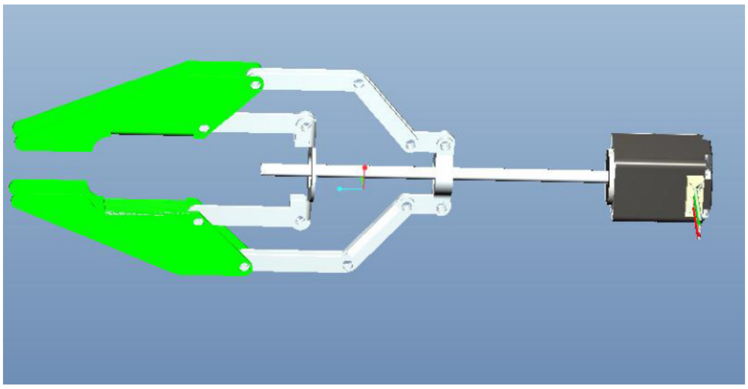


Figure 9.1.1 Robotics gripper

Features and Comments

- It uses the linear actuator as a driver
- Large opening and closing
- The parallel hand movements help effective gripping
- Designed with sheet metal
- Inexpensive design and manufacturing cost
- Smooth movement
- Light weight

Figure 9.1.2 below shows another type of gripper.

Figure 9.1.2 Robotics gripper

Features and Comments

- It uses the threaded wheel and threaded axis as working mechanism
- Parallel gripping action
- Uses solid metal
- Easy to design but manufacturing cost is high
- Comparatively heavy

Figure 9.1.3 below shows a flexible gripper using cylinders.

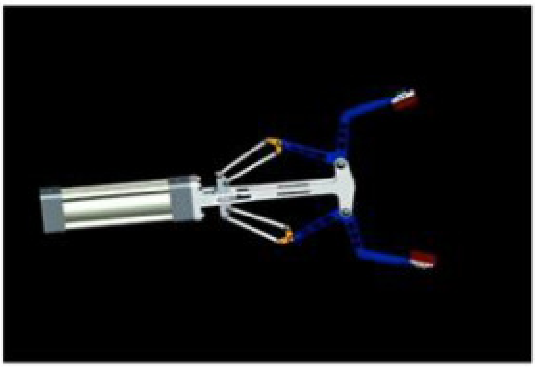


Figure 9.1.3 Cylinderical gripper

Features and Comments

- It uses the linear actuator as driving mechanism
- Simple design and flexibility in manufacturing
- Both sheet metal and solid metal can be used
- Dimension is long on one direction
- Angular gripping and appropriate for cylindrical objects

Figure 9.1.4 below shows an angular gripper type.

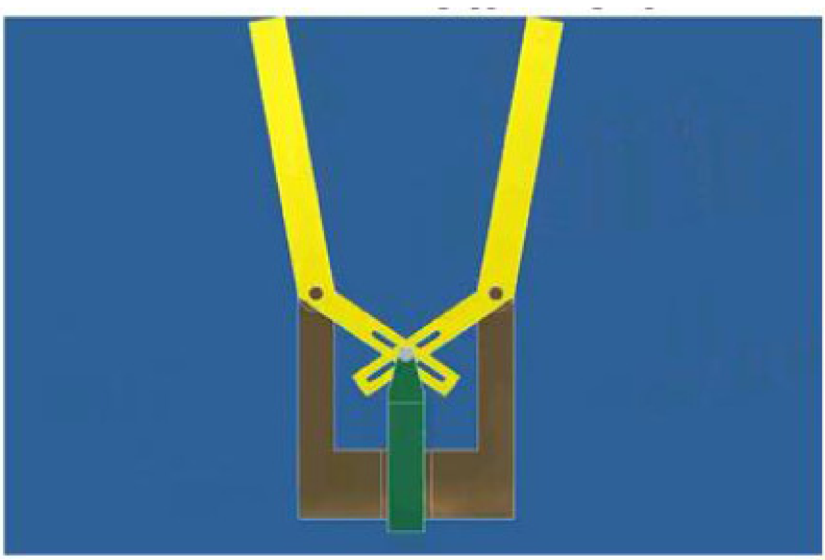


Figure 9.1.4 Angular Gripper

Features and Comments

- It uses the linear actuator

- The simplest design among all
- It has angular gripping action
- Limited opening and closing action
- Difficulty in gripping the object
- Contain few number of parts

The basic features of all the individual grippers are taken in consideration. The selection is made among this gripper in such a way that it meets all the requirements for the application. It must be simple, convenient, light weight and easy to manufacture. Based on these facts, the first gripper is decided to be finalized.

9.2 Model Design and Technical Drawing

The first Figure 9.2.1 shows the closing position of the gripper. The gripping action is flexible for any size of an object due to the parallel movement of the hands. The working mechanism of the gripper is based on the formation of parallelogram by four joints. The gripping action takes place due to the sliding of threaded bolt in a linear actuator which changes the orientation of the parallelogram.

The dimension of the gripper at closing position is about 128 mm X 63 mm.

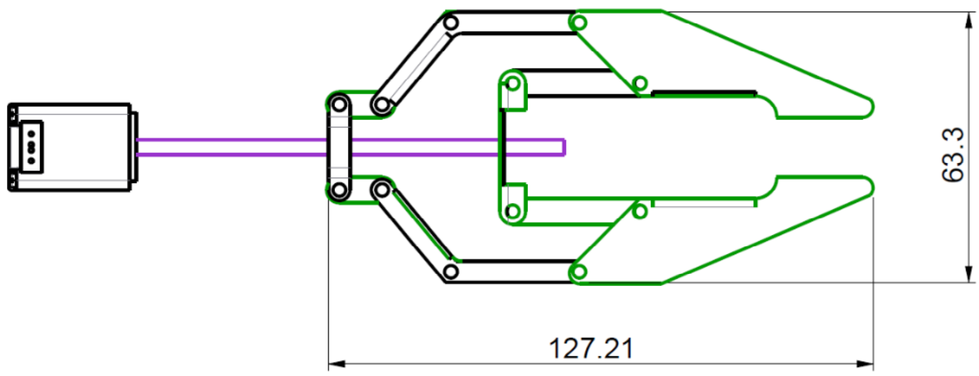


Figure 9.2.1 the dimension of the gripper at opening position is about 86.9 mm X 115.93 mm

Figure 9.2.2 below shows the dimensions of gripper.

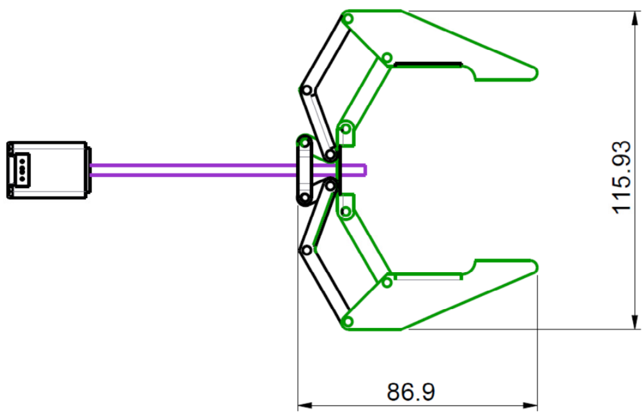


Figure 9.2.2 Gripper dimension

This mechanical gripper is a linear actuator and all the necessary studies and technical documentation are given. Another option for the gripper is magnetic gripper. The magnetic gripper can be bought from the market and, simply be assembled to the arm which saves the time and the cost. But the lack of time and availability of the resources makes the construction of the gripper to be terminated. It is decided not to use any kind of gripper in this arm.

10. Conclusion

A control system for controlling the Robotic Arm manipulator was studied theoretically in detail. At the beginning, a solid plan was made to write about details, but due to the circumstances encountered, a frequent change is made in the plan. Detailed studies were made to find the best possible solution for understanding a control system, which includes selection of components like PLC, PLC's components, gripper, motor controller, power supply units etc. Most of the time of the writing was spent for understanding the control components, which is the main part of this thesis. For the gripper, theoretical studies and required documentation were read. Some of the additional components like control pendant, integration circuit board, voltage regulator and support system were understood during the different stages of writing.

The programming was studied according to the operating principle which was decided in this thesis i.e. manual operational modes and automatic operational modes. The manual operational modes programmed in the PLC to control the positive and negative movement of all axes was successfully written in the robotic arm explanation. But, for the automatic modes, the programming was basic with very few features, but this shows the possibilities for the further programming in future to obtain a complete control system with automatic mode of operation for a robotic arm.

Conclusively, the theoretical writing was worthful to understand different automated components. During this writing work, it encounters a number of problems regarding the technical difficulties, and some problems due to lack of understanding. This theoretical approach teaches much about dealing with a problem and finding the solution. The wiring and installation were shown using figures, which makes one more skilful in understanding tools and equipment. The other thing, this theory has completely different, was the programming software “TIA Portal V11 Simatic”. In control system course, there is less about PLC programming software, but this theory detail helps to learn more about it. This theory writing about the PLC for the installation of the control system has given a lot about the learning approach and helps to do more about this subject in the future.

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