Controlling a Robotic Arm Manipulator with a PLC

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UNIVERSITY OF APPLIED SCIENCES

Bachelor's thesis

Degree Programme in Mechanical Engineering and Production Technology

Riihimäki

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ABSTRACT

Riihimäki
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Subject of Bachelor's thesis: Controlling a Robotic Arm manipulator with a PLC

ABSTRACT

This thesis was commissioned for HAMK University of Applied Sciences with the aim of designing a control system for a robotic arm. The Robotic Arm in this case was from HAMK's Laboratory for Automation, Riihimäki which was designed by Nicolas Mustaka (an exchange student from Greece, 2009).

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

The pre-existing Robotic Arm was designed to work manually using potentiometers and a replacement was made with a 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 designed with a PLC needs additional electronic components, such as a DC motor controller and control pendent. The parts selected were those that met specifications and designed requirements. The majority of the time was spent on wiring and installation. During the installation, consideration was made for a safe and effective design. In this project, the design and construction of the gripper was not completed as planned at the beginning, only the research and theoretical design approach was made. After the complete installation of all the hardware sections, the programming was the last to be completed. The principles for manual modes of operation and automatic modes of operation were 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 were accomplished with a successful demonstration.

The complex programming was possible in the PLC for the automatic mode of operation. It was 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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CONTENTS

1 INTRODUCTION ... 1

2 BACKGROUND OF THE PROJECT ... 2

2.1 Pre-existing Robotic Arm ... 2
2.2 Working Mechanism ... 3

3 MAIN COMPONENTS ... 3

3.1 PROGRAMMABLE LOGIC CONTROL(PLC) ... 3
3.2 DC MOTOR CONTROLLER ... 5
3.3 DC motors ... 5
3.4 Potentiometer ... 6

4 FUNCTIONAL DESCRIPTION ... 7

4.1 Mathmatical Background ... 8
4.2 Alternative solution A ... 12
4.3 Alternative Solution B ... 13

5 SYSTEM DESCRIPTION ... 14

5.1 Inputs ... 15
5.1.1 Control Pendent ... 15
5.1.2 Potentiometer ... 16
5.2 Outputs ... 16

6 REAL COMPONETS ... 17

6.1 PLC Components ... 17
6.1.1 Central Processing Unit (CPU) ... 17
6.1.2 Signal Modules ... 18
6.1.3 Power Supply Unit ... 20
6.2 Potentiometer ... 21
6.3 DC motor Controller ... 22
6.4 Voltage regulator ... 24
6.5 DC Motor ... 25
6.6 Linear Actuator ... 26
6.7 Control pendent ... 26

7 CIRCUIT AND WIRING DESIGN ... 27

7.1 Circuit board ... 27
7.2 Bridge Board ... 30
7.3 Control Pendent Circuit ... 31
7.4 The commissioning measurements on the robot drive circuit ... 33

8 PROGRAMMING ... 35

8.1 Programming tool ... 35
8.2 Defining Inputs and Outputs variables ... 35
8.2.1 Input variables ... 36
8.2.2 Output variables ... 37

8.3 Analog Signal processing 39
8.4 Manual Control Modes 42
8.5 Automatic Movement 44

9 DESIGN AND CONSTRUCTION OF GRIPPER 46

9.1 Gripper Design 46
9.2 Model Design and Technical Drawing 47

10 CONCLUSION 49

REFERENCES 50

Appendix 1 Programming for Manual mode

Appendix 2 Programming for Automatic mode

Appendix 3 DC Motor Controller Manual

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 proposes.

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 in industrial purposes for fast and reliable performance, helping for mass productions.

This thesis is a project based thesis. The project was done for the HAMK Electronic Laboratory for the installation of a control system in a robotic arm. Additionally, the necessary research was 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 PROJECT

This thesis topic was proposed by the HAMK Laboratory for Automation in the Industrial Technology Research and Education Unit, Riihimäki with the aim to develop a 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 designing of a gripper as an end effector. During this designing process, a student is supposed to use his/her engineering knowledge. This thesis includes various aspects of Mechanical Engineering; automations (control system), concepts of electronic drives, general engineering subjects, parts design (strength of materials) and mathematics etc. The result is that this thesis helps to develop the skills of practical knowledge about the subject matter in real life.

2.1 Pre-existing Robotic Arm

The Robotic Arm shown in figure 2.1 is from the HAMK laboratory which was designed and constructed by Nicolas Mustaka (an exchange student from Greece, 2009). This robot has six 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.

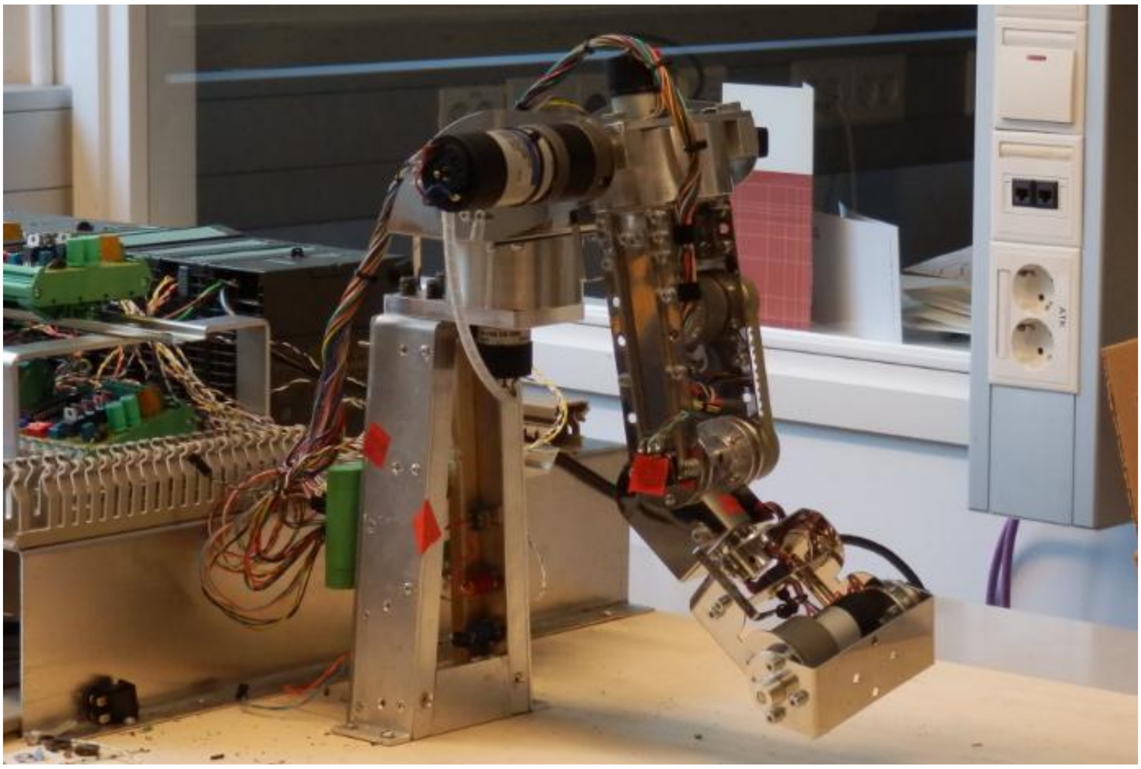


Figure 2.1 HAMK Electronic Laboratory Robotic Arm

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 design requirement is set according to the need of this project. In this part, the main basic requirements are the construction 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 LOGIC CONTROL(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 it 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.

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

(The Phoenix Contact Online Catalog)

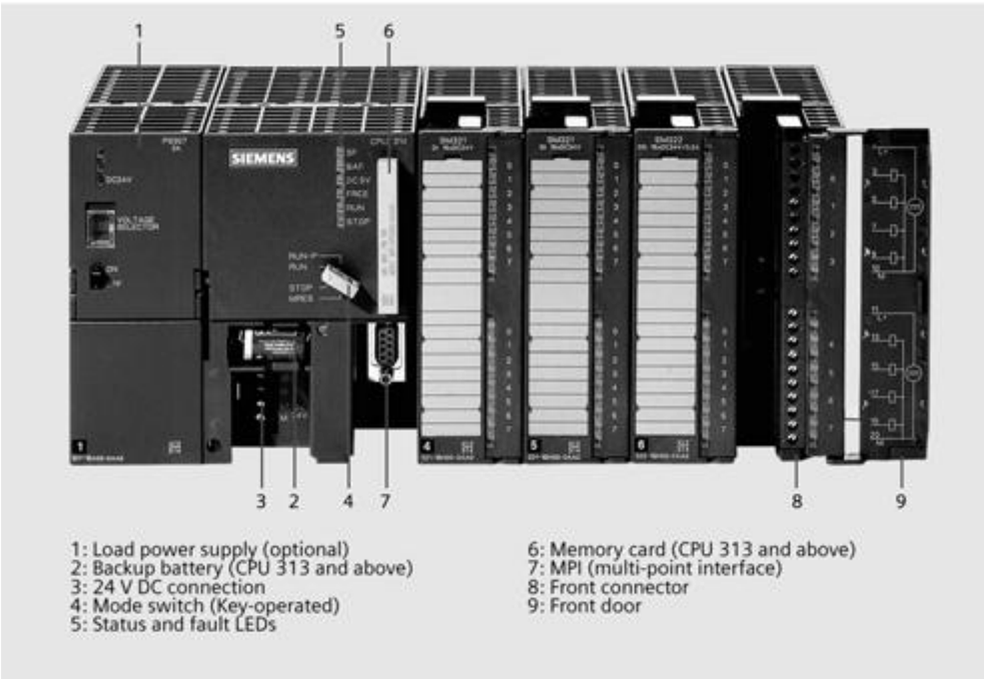


Fig 3.1.b Automation system SIMATIC S7-300*(Siemens Product Specification, 2003)*

3.2 DC MOTOR CONTROLLER

A **motor controller** is a device or 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	24 Vdc
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.

In this control system, the motor will run in both directions and in certain applications with variable speeds.

Nominal voltage +12V; +24V
Nominal power 40W-100W;
Nominal current +2A…. 4A

Figure 3.4 Dayton DC Gear motor ***(Dyton)***

3.4 Potentiometer

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 3.5 a typical single-turn potentiometer ***(Wikipedia)***

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 we used the rotary potentiometers 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 Armin all directions.

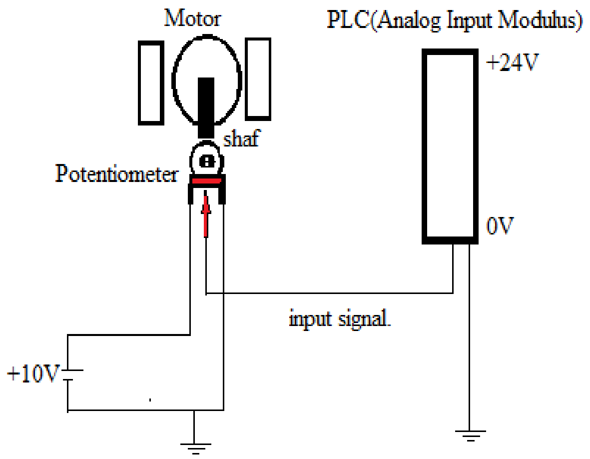


Figure 2.2 Positioning system using potentiometer

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 2.2 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 valve 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 give 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 preforms 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 Mathmatical Background

A standard mathematic tool used in robotics for computing the position and orientation of the end effector 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.

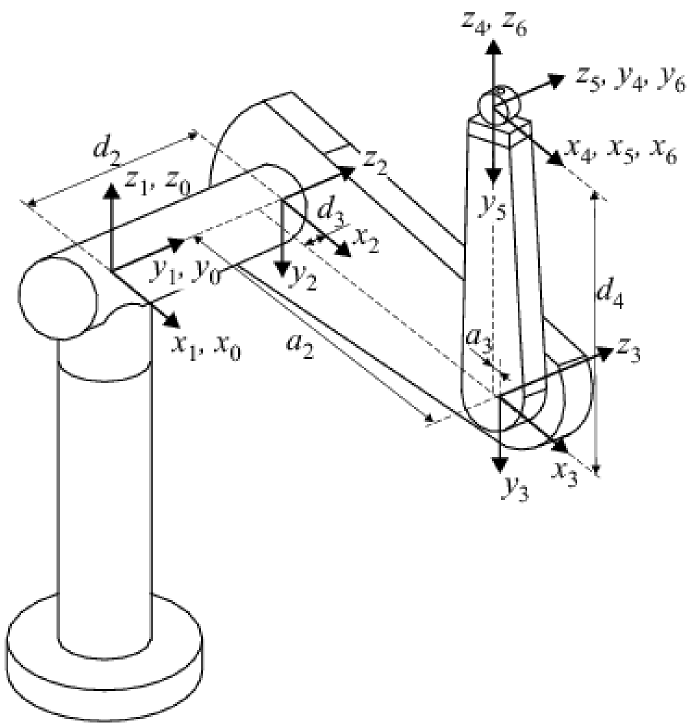


Figure 4.1 Constraints of DH parameters *(Lavalle,2006)*

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
ϴi = angle (Xi-1, Xi) about Zi
For every joint, among these four parameters, only two of them is variable; di for the prismatic joint (linear joint) and ϴi for the rotatory joint.
In the current case, the robot only has rotatory joints, so the value of di = 0 in every case and ϴi 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)*

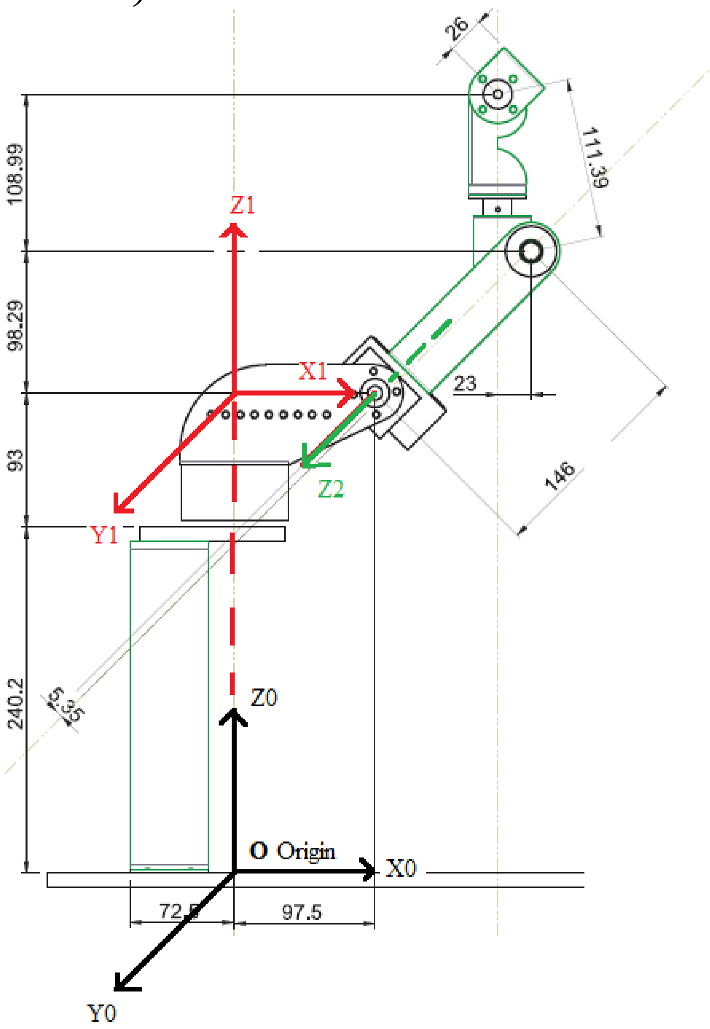


Figure 4.1.a Dimension of the Robotic Arm

The six angular variables can define 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 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 follows:

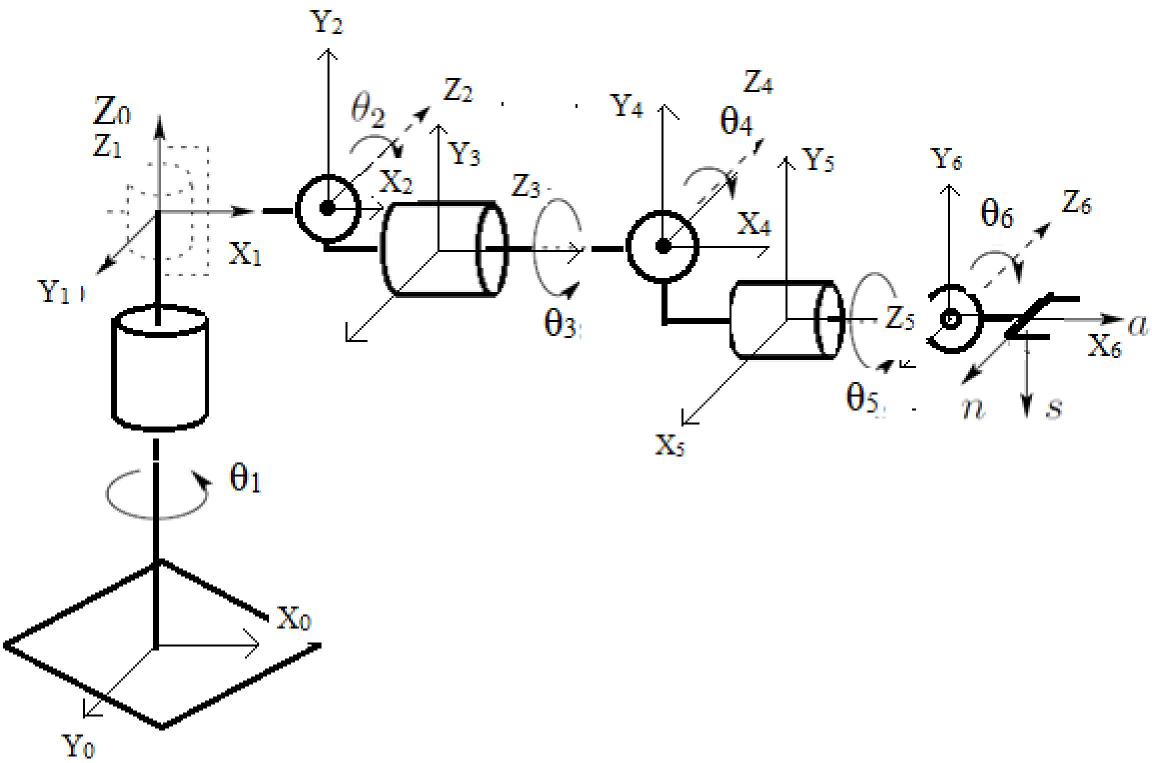


Figure 4.1.c Free Body Diagram (FBD) defining DH parameters

From the above free body diagram (FBD), the HD parameters for each joint can be listed below.

Table 4.1 DH parameters for the Robotic Arm

Joint link (i)	Angle two axis (α_i)	Perpendicular distance between two axis (a_i)	Displacement(d_i)	Angular Rotation (θ_i)
1	0	0	333mm	0
2	-90	97.5mm	0	θ_1
3	90	5.53	0	θ_2
4	-90	146	0	θ_3
5	90	23	0	θ_4
6	-90	109	0	θ_5
7	0	0	26	θ_6

The transformation matrix for each joint can be formed using the given formula.

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

Substituting the DH parameter values, then each joint gives a set of 4x4 matrixes which defines the co-coordinative system for that joint. *(Paul, 1981)*

$$A_2(\theta_2) := \begin{pmatrix} \cos(\theta_2) & -\sin(\theta_2) & 0 & 97.5 \\ 0 & 0 & 1 & 0 \\ -\sin(\theta_2) & -\cos(\theta_2) & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$A_3(\theta_3) := \begin{pmatrix} \cos(\theta_3) & -\sin(\theta_3) & 0 & 5.5 \\ 0 & 0 & -1 & 0 \\ \sin(\theta_3) & \cos(\theta_3) & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$A_4(\theta_4) := \begin{pmatrix} \cos(\theta_4) & -\sin(\theta_4) & 0 & 97.5 \\ 0 & 0 & 1 & 0 \\ -\sin(\theta_4) & -\cos(\theta_4) & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$A_5(\theta_5) := \begin{pmatrix} \cos(\theta_5) & -\sin(\theta_5) & 0 & 97.5 \\ 0 & 0 & -1 & 0 \\ \sin(\theta_5) & \cos(\theta_5) & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$A_6(\theta_6) := \begin{pmatrix} \cos(\theta_6) & -\sin(\theta_6) & 0 & 97.5 \\ 0 & 0 & 1 & 0 \\ -\sin(\theta_6) & -\cos(\theta_6) & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

The position and the orientation of the point P can be calculated by multiplying all the translation matrixes of the joints. This can be represented as below.

Total transformation (T) = $A_2(\theta_2)\cdot A_3(\theta_3)\cdot A_4(\theta_4)\cdot A_5(\theta_5)\cdot A_6(\theta_6)$

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 and to make the program in the PLC.

4.2 Alternative solution A

The PLC program can uses the analog voltage value from the potentiometer and record every angular positions. 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 same. This process takes parallel to the every axis and it defined 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 gives 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)

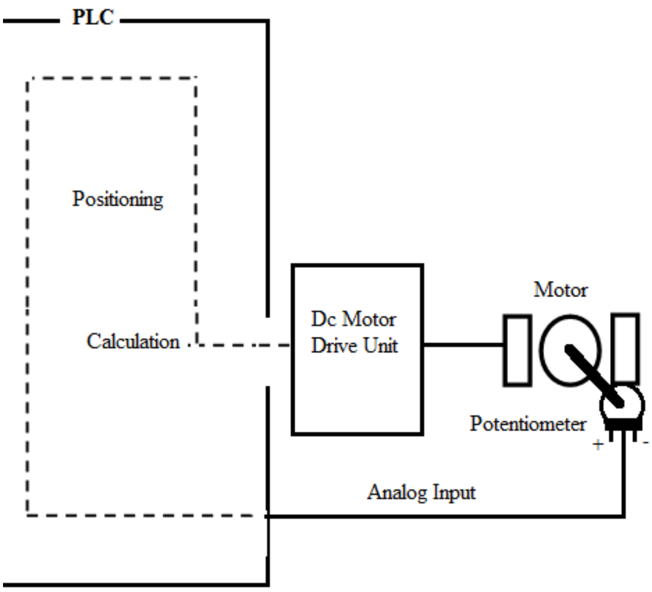


Figure 4.2 Diagram showing the use of DC motor controller

4.3 Alternative Solution B

This method for controlling the position of the arm is similar to the one which is described above. Instate of DC motor controller, in this method, a power amplifier is used. For driving the motor, the analog output is power amplified. 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.

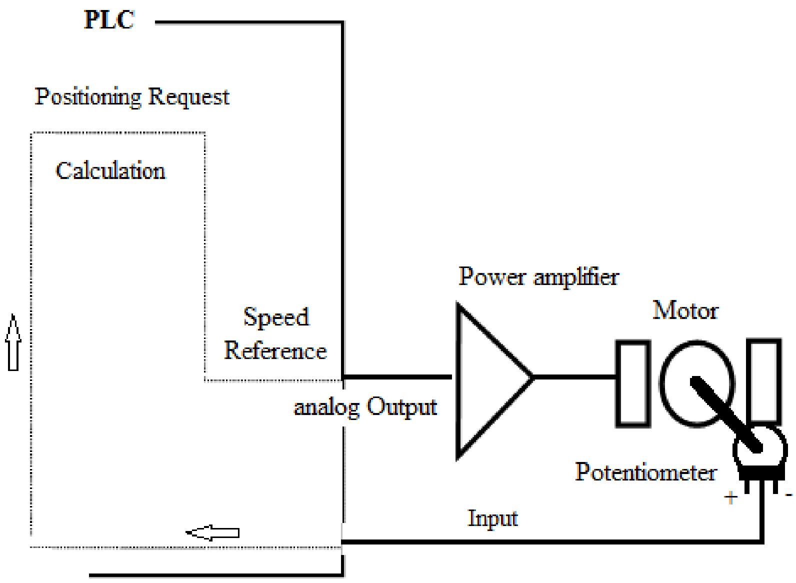


Figure 4.3 Diagram showing the use of Power Amplifier

5 SYSTEM DESCRIPTION

The figure 5 shows the layout connection between the components. The hardware components for this control system is designed to operates in; the automatic modes and the manual modes.

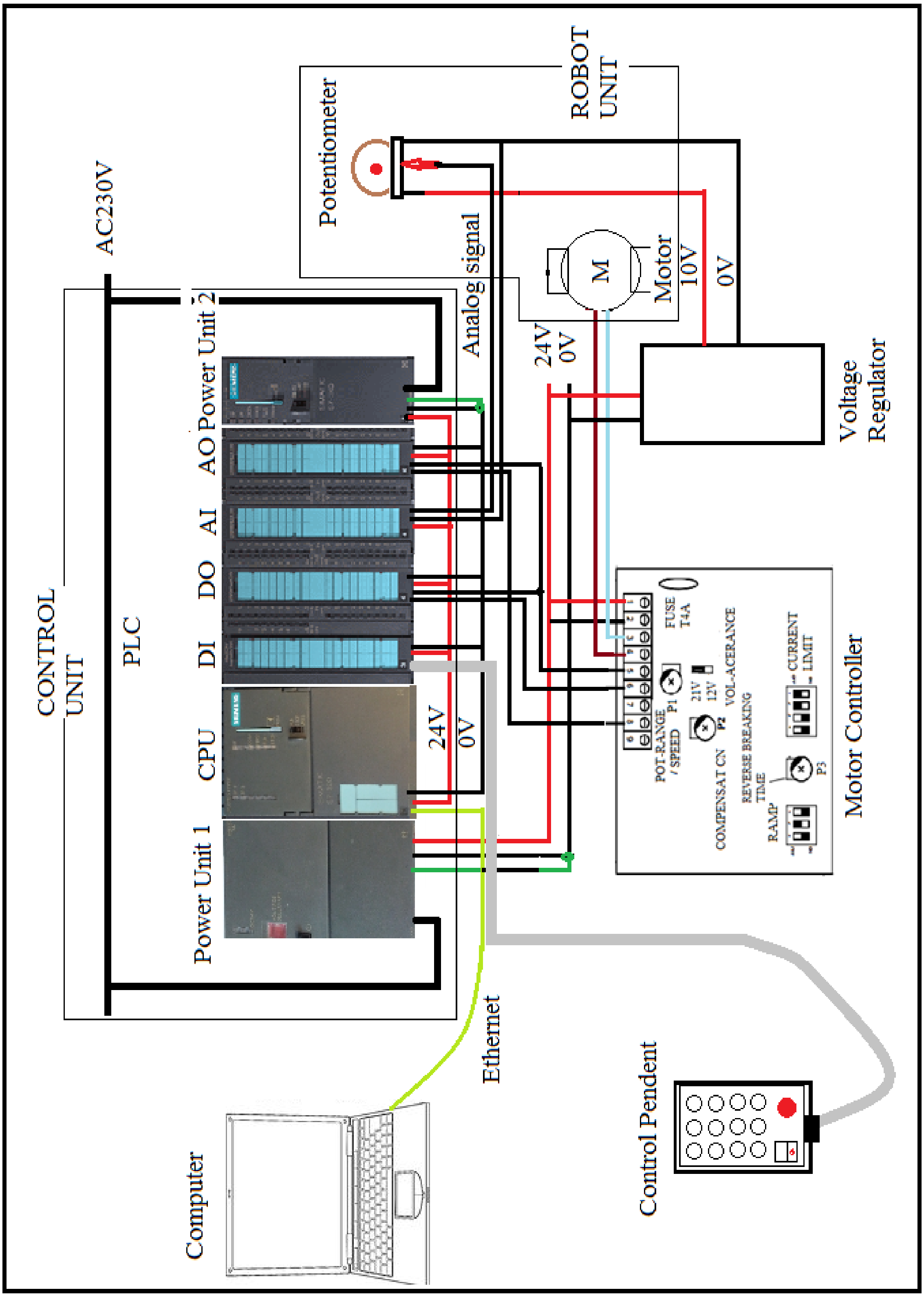


Figure. 5 Layout of all the connecting Components

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 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 is used in the box.

5.1.1 Control Pendent

All the inputs from the control pendent is digital inputs

Table 5.1.1 Input variables

Control Pendent		PLC unit Location	Description
Name	Type		
Btn_1	Pushbutton	SM 321; DI 16 x 24 VDC	Push button to controlled the +ve movement of axis 1
Btn_2	Pushbutton	SM 321; DI 16 x 24 VDC	Push button to controlled the -ve movement of axis 1
Btn_3	Pushbutton	SM 321; DI 16 x 24 VDC	Push button to controlled the +ve movement of axis 2
Btn_4	Pushbutton	SM 321; DI 16 x 24 VDC	Push button to controlled the -ve movement of axis 2
Btn_5	Pushbutton	SM 321; DI 16 x 24 VDC	Push button to controlled the +ve movement of axis 3
Btn_6	Pushbutton	SM 321; DI 16 x 24 VDC	Push button to controlled the -ve movement of axis 3
Btn_7	Pushbutton	SM 321; DI 16 x 24 VDC	Push button to controlled the +ve movement of axis 4
Btn_8	Pushbutton	SM 321; DI 16 x 24 VDC	Push button to controlled the -ve movement of axis 4
Btn_9	Pushbutton	SM 321; DI 16 x 24 VDC	Push button to controlled the +ve movement of axis 5
Btn_10	Pushbutton	SM 321; DI 16 x 24 VDC	Push button to controlled the -ve movement of axis 5
Btn_11	Pushbutton	SM 321; DI 16 x 24 VDC	Push button to controlled the +ve movement of axis 6
Btn_12	Pushbutton	SM 321; DI 16 x 24 VDC	Push button to controlled the -ve movement of axis 6
Eme_0	Emergency Switch	SM 321; DI 16 x 24 VDC	When emergency switch is pressed, one signal is sent to PLC to know the condition of emergency.

5.1.2 Potentiometer

The signal from the potentiometer is the analog inputs for the PLC.

Table 5.1.2 Input variables

Name	Type	PLC Unit Location	Description
Pot_1	Potentiometer	SM 331; AI 8 x 12 bit	Potentiometer reading of Axis 1
Pot_2	Potentiometer	SM 331; AI 8 x 12 bit	Potentiometer reading of Axis 2
Pot_3	Potentiometer	SM 331; AI 8 x 12 bit	Potentiometer reading of Axis 3
Pot_4	Potentiometer	SM 331; AI 8 x 12 bit	Potentiometer reading of Axis 4
Pot_5	Potentiometer	SM 331; AI 8 x 12 bit	Potentiometer reading of Axis 5
Pot_6	Potentiometer	SM 331; AI 8 x 12 bit	Potentiometer reading of Axis 6

5.2 Outputs

The outputs 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 is used from the PLC.

Table 5.2 Output Variables

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

6 REAL COMPONETS

The design requirement is set according to the need of this project. In this part, the basic requirements are a control system design and a gripper design. Both of them have completely deferent requirements which consists the physical components and it 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, 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 HAMK Laboratory. For this application, SIMATIC S7-300 PLC is used. 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 hardware like Phoenix Contacts and FESTO, an embedded CPUs and I/O units are used. 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.
(Wikipedia)

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
   - 8 inputs in 4 channel group
   - Programmable measurement type of each channel group
     - 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 type 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 more 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)

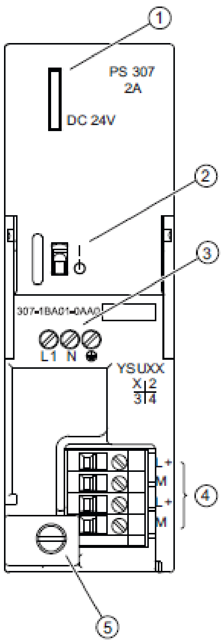


Figure 6.1.3a Power Supply module, 2A

(Siemens Module Specifications 2001, 27)

<u>Properties:</u>

- Output current 2 A
- Output voltage 24 VDC; short circuit-proof, open circuit-proof
- Connecting to single phase AC mains (rated input voltage 120/230VAC, 50/60 Hz)
- Safety isolation to EN 60
- Can be used as load power supply

① "24 VDC output voltage present" dis
② 24 VDC On/Off switch
③ Mains and protective conductor terr
④ Terminals for 24 VDC output voltag
⑤ Strain-relief

b) Power supply module PS 307; 5 A; (6ES7307-1EA01-0AA0)

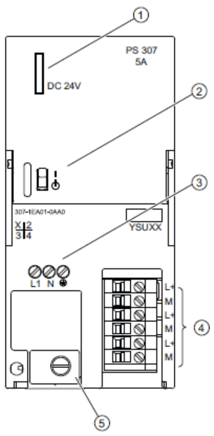


Figure 6.1.3b Power Supply module, 5A

(Siemens Module Specifications 2001, 32)

<u>Properties:</u>

- Output current 5A
- Output voltage 24 VDC; short circuit-proof, open circuit-proof
- Connection to single phase AC mains (rated input voltage 120/230 VAC, 50/60 Hz)
- Safety isolation EN 60 950
- May be used as load power supply

6.2 Potentiometer

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

Figure 6.2 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°C+70°C

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 use 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 staring torque. Loading of the motor can be compensated with inbuilt RI-adjustment. There are 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 DC Motor Controller

(Electromen Oy, n.d..)

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 limits the output current. The adjustment can be made by the right arrangement of the DIP-switches. The configuration of the DIP-switches can be shown below.

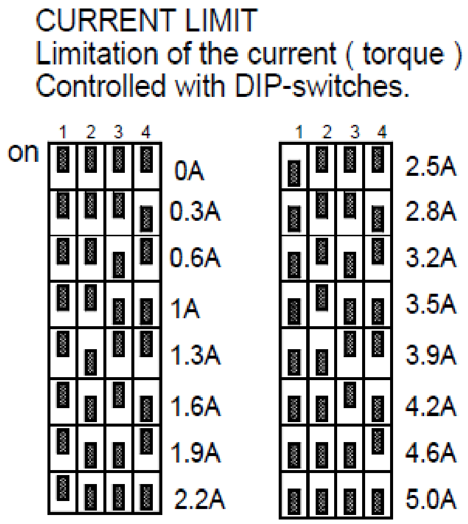


Figure 6.3.a DIP-switches for controlling the current

(Electromen Oy, n.d..)

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.

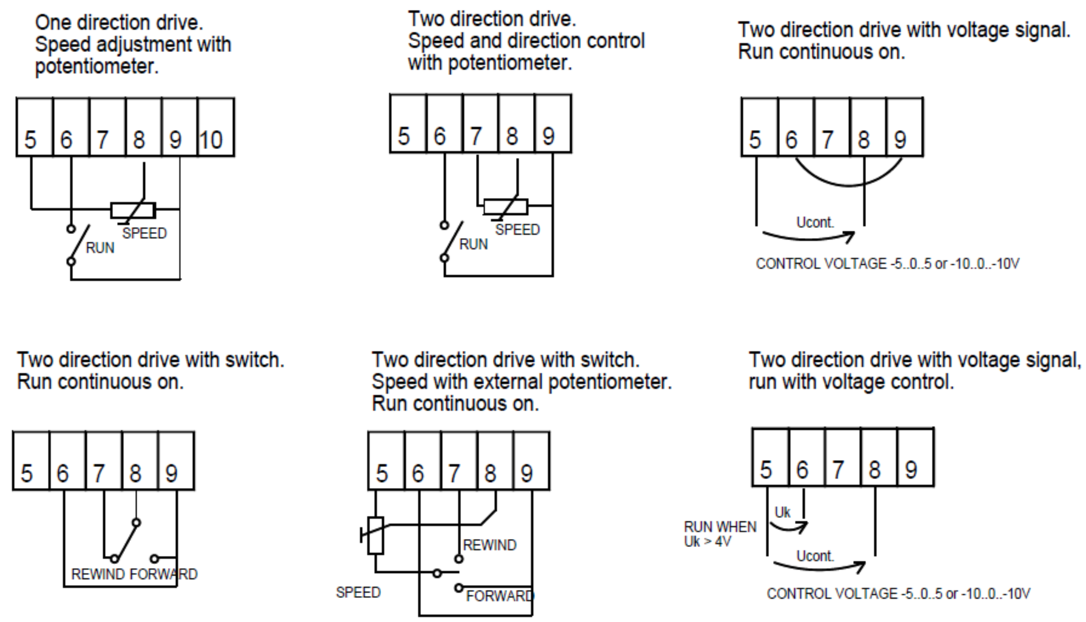


Figure 6.3.b EI- connection example

(Electromen Oy, n.d..)

6.4 Voltage regulator

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 shown below

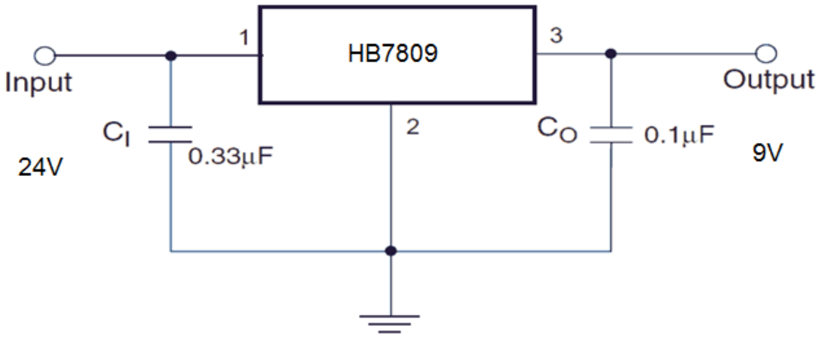


Figure 6.4.a Voltage Regulator Circuit diagram

The real construction of the voltage regulator board is constructed using the above wiring diagram.

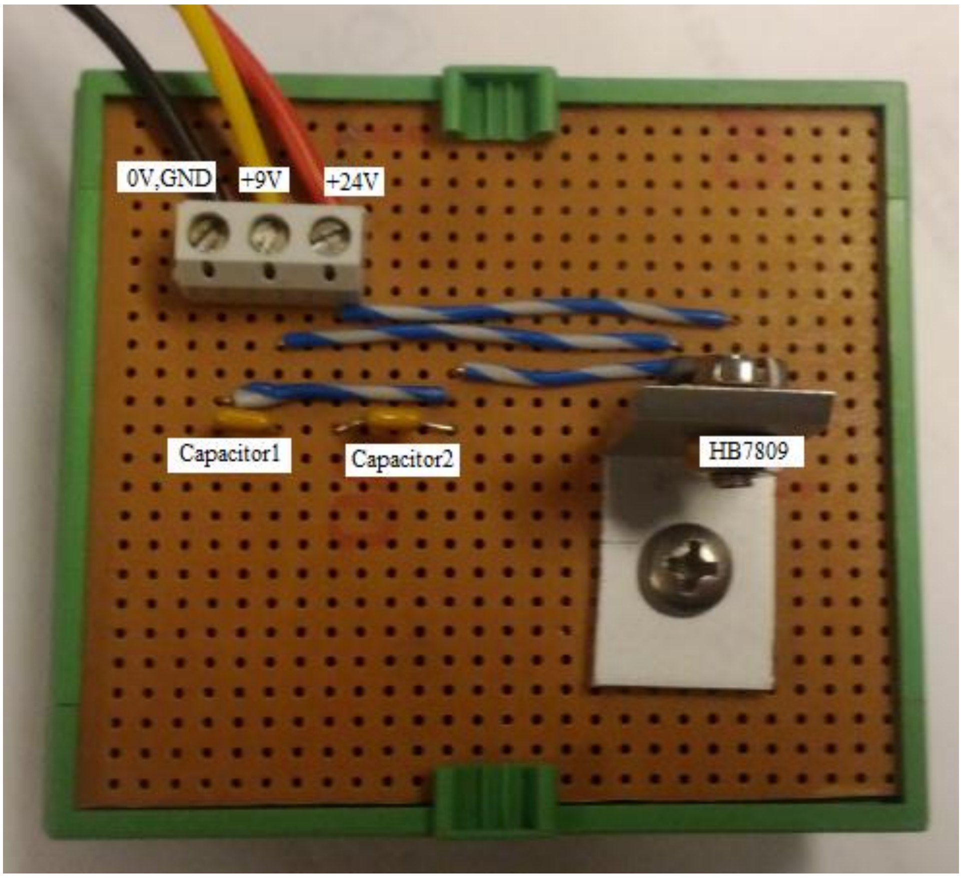


Figure 6.4.b Voltage Regulator Board

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. The gear motor E192.24.200 is used in only one axis whereas the motor type RH 158.24.200 is used in remaining five axes.

Motor (RH158.24.200)	**Motor (E192.24.200)**
 **Figure 6.5.a DC gear motor (RH158.24.200)** *(micromotors, n.d..)*	 **Figure 6.5.b DC gear motor (E192.24.200)** *(micromotors, n.d..)*
Features 1. VDR interference suppression on the collector 2. Direction of the rotation depends on the polarity 3. Maximum radial shit load: 50N 4. Maximum axial shaft load: 10N 5. Temperature range: -20°C/60°C 6. Weight: Approx. 190g	**Features** 1. VDR interference suppression on the collector 2. Direction of the rotation depends on the polarity 3. Maximum radial shit load: 200N 4. Minimum axial shaft load: 100N 5. Temperature range: -20°C/60°C 6. Weight: Approx. 385/480g
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..)*	**Technical Details** Nominal voltage:24V Gear ratio: 125 Maximum torque: 300 Ncm Speed (No Load) : 33 rmp Speed (at Max torque) : 26 rmp *(micromotors, n.d..)*

6.6 Linear Actuator

Linear Actuator is designed in such way that it can transmit an object linearly with the help of screw system as shown in the figure 6.6. The threaded axis is rotates by the help of motor and due to the screw on the axis, it slide back and forth. With the help of linear actuator, a mechanical system can be designed for gripping objects. The light weight and electrically controlled drive will be a best choice because it can be easily controllable and does not need additional pneumatic power and pneumatic components.

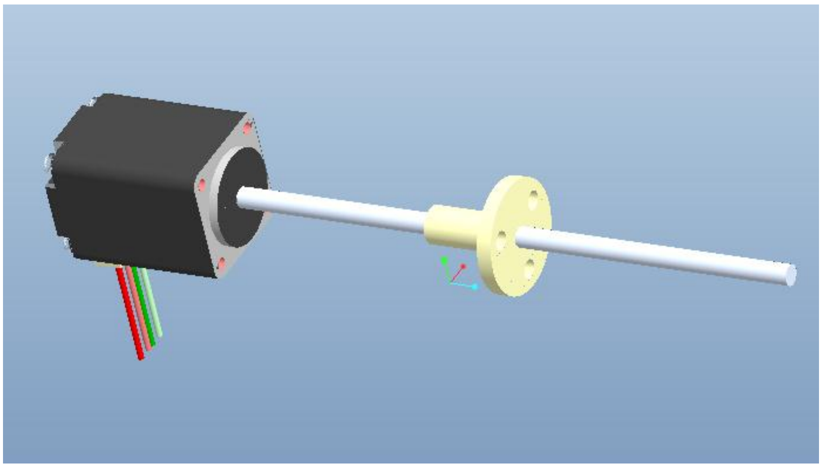


Figure 6.6 3D Model of Linear Actuator (Haydon 21000 Series)

6.7 Control pendent

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

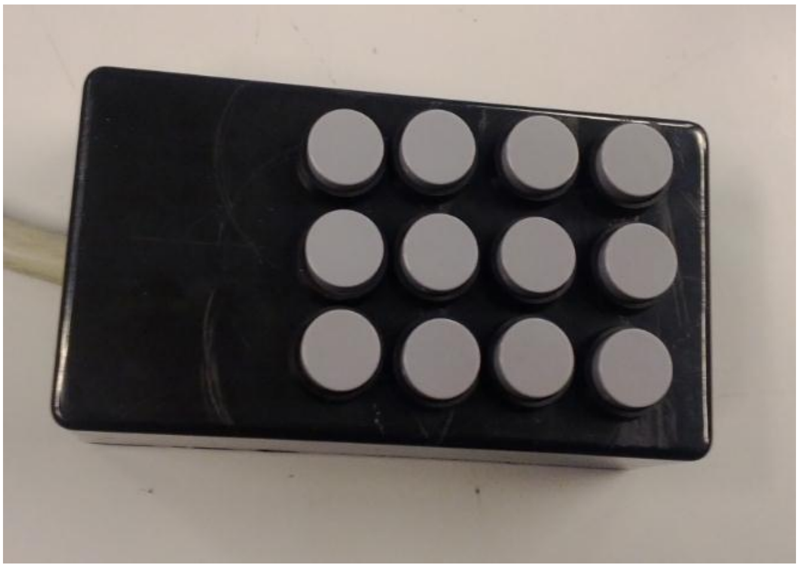


Figure 6.7 Control pendent for controlling the movements of the Robotic Arm

7 CIRCUIT AND WIRING DESIGN

7.1 Circuit board

The real circuit was designed on a wooden board as shown in the figure 7.1. All the control system units and Robotic Arm were fixed in the same the 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.

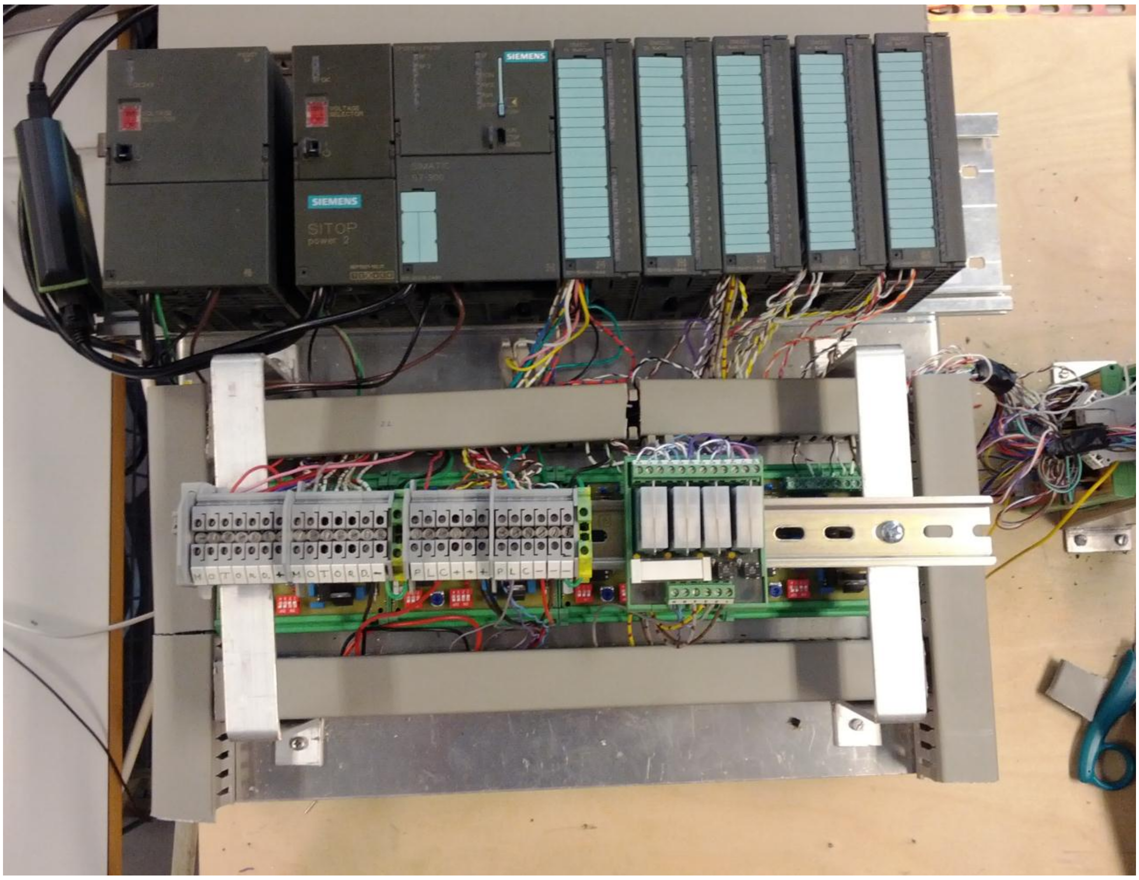


Figure 7 Wiring connections between PLC and motor controller.

Table 7. Wiring Connection table

PLC				Wiring		D.C Motor Drive				Wiring		Robot	
PLC Unit	I/O Address	I/O Types	Connection Number	Color	Type	Connection Number	Input Name	Output Name	Connection Number	Color	Type	Polarity	Motors Axis
SM 332; AO 4 x 12 Bit	QV0 CH0	Analog output	3	Red	Twisted 0.2 mm²	8	Ref. in Control Gnd	Motor(+)	4	Red	Twisted0.2mm²	+	Axis1
SM 332; AO 4 x 12 Bit	M_{ANA} CH0	Gnd	6	White	Twisted 0.2 mm²	5	Gnd	Motor(-)	3	White	Twisted0.2mm²	-	Axis1
SM 322; DO 16 x DC 24	1L+	Digital Output	2	Black									Axis 1
SM 332; AO 4 x 12 Bit	QV1 CH1	Analog Output	7	Orange	Twisted 0.2 mm²	8	Ref. in Control Gnd	Motor(+)	4	Orange	Twisted0.2mm²	+	Axis2
SM 332; AO 4 x 12 Bit	M_{ANA} CH1	Gnd	10	White	Twisted 0.2 mm²	5	Gnd	Motor(-)	3	White	Twisted0.2mm²	-	Axis2
SM 322; DO 16 x DC 24	1L+	Digital Output	3	Red									Axis2
SM 332; AO 4 x 12 Bit	QV2 CH2	Analog Output	11	Green	Twisted 0.2 mm²	8	Ref. in Control Gnd	Motor(+)	4	Green	Twisted0.2mm²	+	Axis3
SM 332; AO 4 x 12 Bit	M_{ANA} CH2	Gnd	14	White	Twisted 0.2 mm²	5	Gnd	Motor(-)	3	White	Twisted0.2mm²	-	Axis3
SM 322; DO 16 x DC 24	1L+	Digital Output	4	Green									Axis3
SM 332; AO 4 x 12 Bit	QV3 CH3	Analog Output	15	Black	Twisted 0.2 mm²	8	Gnd	Motor(+)	4	Black	Twisted0.2mm²	+	Axis4
SM 332; AO 4 x 12 Bit	M_{ANA} CH3	Gnd	18	White	Twisted 0.2 mm²	5	Ref. in Control Gnd	Motor(-)	3	White	Twisted0.2mm²	-	Axis4
SM 322; DO 16 x DC 24	1L+	Digital Output	5	white									Axis4
SM 322; DO 16 x DC 24	QV4 CH4	Digital Output	3	Green	Twisted 0.2 mm²	8	Gnd	Motor(+)	4	Green	Twisted0.2mm²	+	Axis5
SM 322; DO 16 x DC 24	M_{ANA} CH4	Digital Output	4	White	Twisted 0.2 mm²	5	Gnd	Motor(-)	3	White	Twisted0.2mm²	-	Axis5
SM 322; DO 16 x DC 24	1L+	Digital Output	6	Red									Axis5
SM 322; DO 16 x DC 24	QV4 CH4	Digital Output	3	Black	Twisted 0.2 mm²	8	Ref. in Control Gnd	Motor(+)	4	Black	Twisted0.2mm²	+	Axis6
SM 322; DO 16 x DC 24	M_{ANA} CH4	Digital Output	4	White	Twisted 0.2 mm²	5	Gnd	Motor(-)	3	White	Twisted0.2mm²	-	Axis6
SM 322; DO 16 x DC 24	1L+	Digital Output	7	Black									Axis6

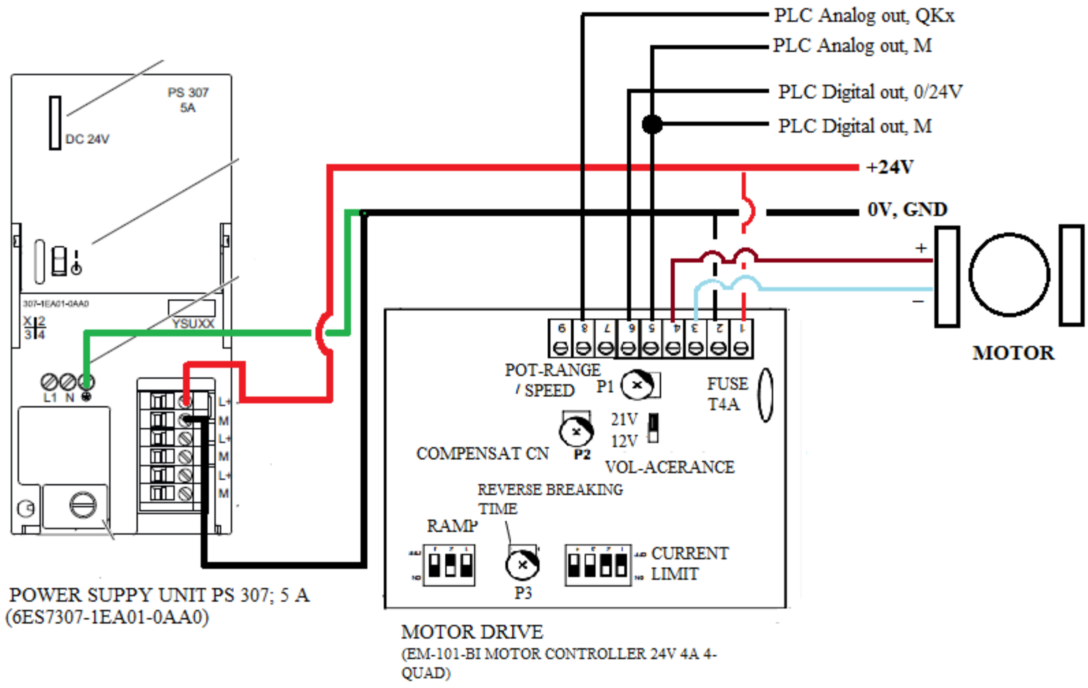


Figure.7.2a. Wiring diagram

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 motor will be controlled by digital signals. The digital signal can drives the motor in two directions but it cannot control the speed the 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 do not much load compare to other motors.

The wiring connection between PLC and motor controller.

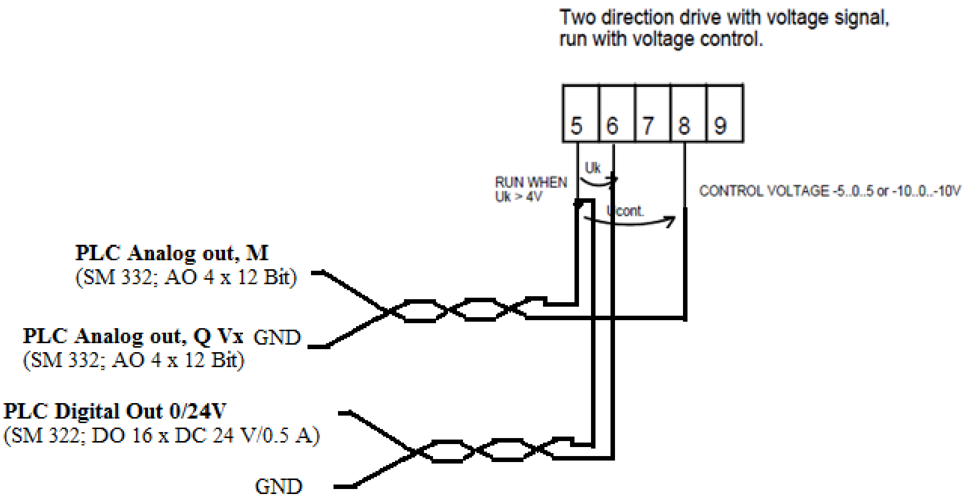


Figure7.2b Motor Controller wiring connection

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 wire can be easily plugged in and plugged out for the convenient wiring. The circuit diagram can be shown below

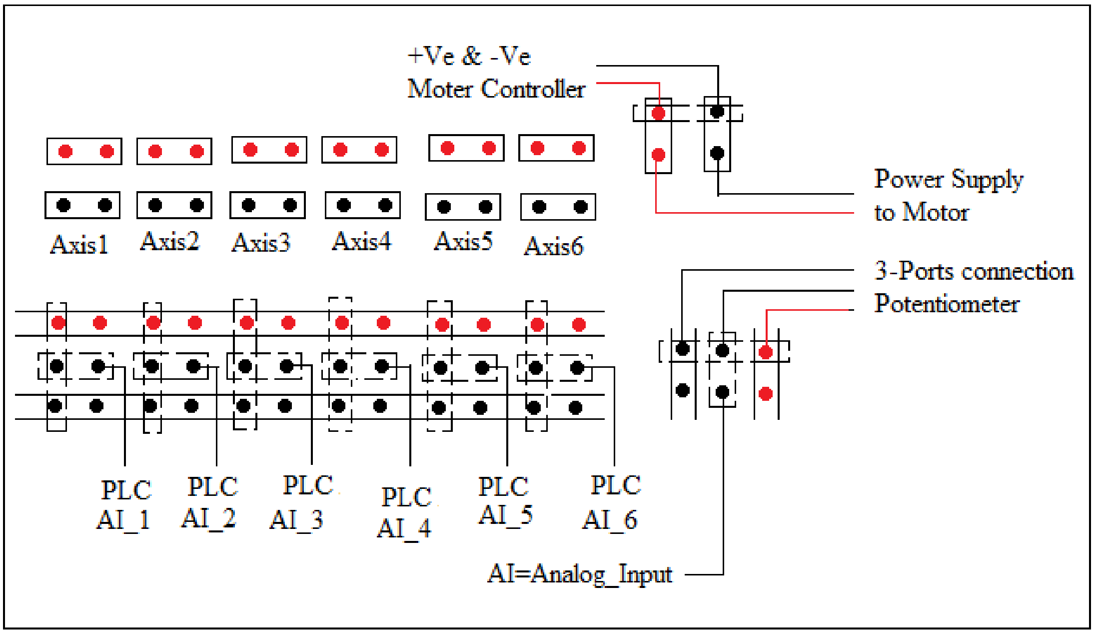


Figure 7.2.a Bridge board Circuit Diagram

The real construction of the bridge board is done using the wiring principle of above diagram.

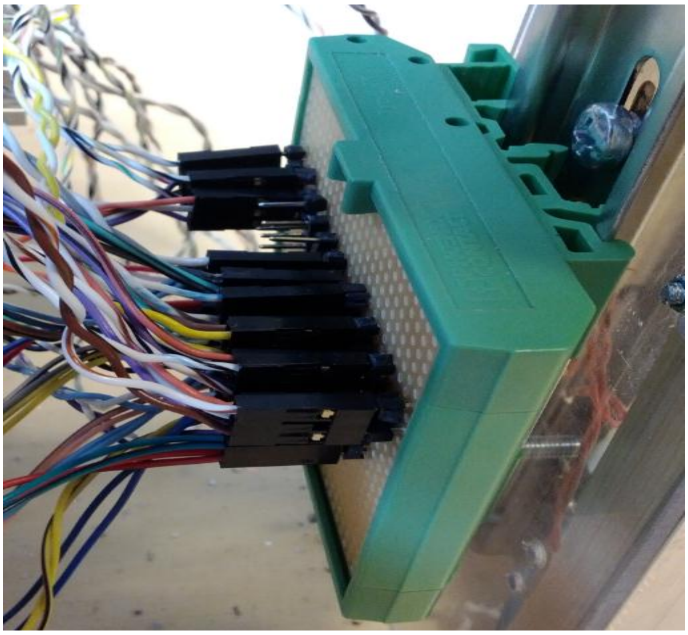


Figure 7.2.b Bridge Circuit Board

7.3 Control Pendent Circuit

Control Pendent is designed with 12 push buttons for driving 6 motor in +ve and -ve direction.

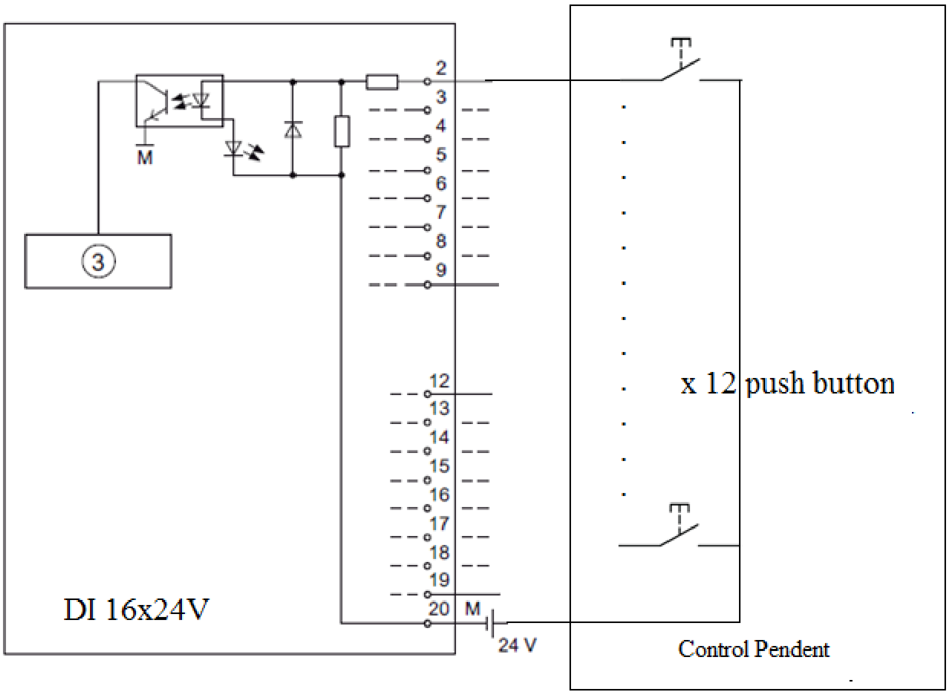


Figure 7.3 Wiring connection of the control pendent and signal module (DI 16x24V)

Table 7.3. Wiring connection between control pendent and PLC

Control Pendent		**Wiring**		**PLC**		**Description**
Name	I/O Type	Color	Type	Unit	Port number	
Push button	Digital Input	Red	$0.4mm^2$	DI 16x 24VDC	2	Driving +ve rotation of motor axis 1
Push button	Digital Input	Green	$0.4mm^2$	DI 16x 24VDC	3	Driving +ve rotation of motor axis 1
Push button	Digital Input	yellow	$0.4mm^2$	DI 16x 24VDC	4	Driving +ve rotation of motor axis 2
Push button	Digital Input	white	$0.4mm^2$	DI 16x 24VDC	5	Driving -ve rotation of motor axis 2
Push button	Digital Input	Black	$0.4mm^2$	DI 16x 24VDC	6	Driving +ve rotation of motor axis 3
Push button	Digital Input	Red	$0.4mm^2$	DI 16x 24VDC	7	Driving -ve rotation of motor axis 3
Push button	Digital Input	Green	$0.4mm^2$	DI 16x 24VDC	8	Driving +ve rotation of motor axis 4
Push button	Digital Input	yellow	$0.4mm^2$	DI 16x 24VDC	9	Driving -ve rotation of motor axis 4
Push button	Digital Input	white	$0.4mm^2$	DI 16x 24VDC	12	Driving +ve rotation of motor axis 5
Push button	Digital Input	Black	$0.4mm^2$	DI 16x 24VDC	13	Driving -ve rotation of motor axis 5
Push button	Digital Input	Red	$0.4mm^2$	DI 16x 24VDC	14	Driving +ve rotation of motor axis 6
Push button	Digital Input	Green	$0.4mm^2$	DI 16x 24VDC	15	Driving -ve rotation of motor axis 6

7.4 The commissioning measurements on the robot drive circuit

Table 7.4 Commissioning measurement table

Unit	Connector number	measured value	Fail / Pass	Notes
Drive 1 EM-101	1	0.0 Ohm to mot+	Passed	
	2	0.0 Ohm to mot-	Passed	
	3	~ Ohm to 4	Failed	Not connected
	4		Failed	Not connected
	5	0.0 Ohm to PLC-	Passed	
	6	0.0 Ohm to PLC out 0	Passed	
	7			
	8	0.0 Ohm to PLC Analog Out 1	Passed	
	9			
	PLC Analog out gnd 6	0.0 Ohm to 5 and PLC -	Passed	
Drive 2 EM-101	1	0.0 Ohm to mot+	Passed	
	2	0.0 Ohm to mot-	Passed	
	3	0 Ohm to 4	Failed	Short circuit
	4		Failed	Short circuit
	5	0.0 Ohm to PLC-	Passed	
	6	0.0 Ohm to PLC out 1	Passed	
	7			
	8	0.0 Ohm to PLC Analog Out 2	Passed	
	9			
	PLC Analog out gnd 10	0.0 Ohm to 5 and PLC -	Passed	
Drive 3 EM-101	1	0.0 Ohm to mot+	Passed	
	2	0.0 Ohm to mot-	Passed	
	3	40 Ohm to 4	Passed	
	4		Passed	
	5	0.0 Ohm to PLC-	Passed	
	6	0.0 Ohm to PLC out 2	Passed	
	7			
	8	0.0 Ohm to PLC Analog Out 3	Passed	

	9			
	PLC Analog out gnd 14	0.0 Ohm to 5 and PLC -	Passed	
Drive 4 EM-101	1	0.0 Ohm to mot+	Passed	
	2	0.0 Ohm to mot-	Passed	
	3	40 Ohm to 4	Passed	
	4		Passed	
	5	0.0 Ohm to PLC-	Passed	
	6	0.0 Ohm to PLC out 3	Passed	
	7			
	8	0.0 Ohm to PLC Analog Out 4	Passed	
	9			
	PLC Analog out gnd 18	0.0 Ohm to 5 and PLC -	Passed	
Drive 5 EM-101	1	0.0 Ohm to mot+	Passed	
	2	0.0 Ohm to mot-	Passed	
	3	40 Ohm to 4	Passed	
	4		Passed	
	5	~ Ohm to PLC-	Failed	Not connected
	6	~ Ohm to PLC out 4	Failed	
	7			
	8			Not decided how to control with digital outputs
	9			
Drive 6 EM-101	1	0.0 Ohm to mot+	Passed	
	2	0.0 Ohm to mot-	Passed	
	3	40 Ohm to 4	Passed	
	4		Passed	
	5	~ Ohm to PLC-	Failed	Not connected
	6	~ Ohm to PLC out 5	Failed	
	7			
	8			Not decided how to control with digital outputs

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 industrial control system with 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
  (TIA Siemens, n.d)

8.2 Defining Inputs and Outputs variables

A list of inputs and outputs 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 maybe 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 7.2 directly represented variable code

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)
L	Long word (64 bits)

There are digital and analog input variables which need to be defined for the programming. On the basic 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 has 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 addresses. For analog inputs,

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 is used for receiving the ON/OFF signal from the control pendent, whereas the analog input modules receives 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 Lists of input variables

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

A_in6	INT	%IW314	Analog input signal of axis 6

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 variables types BOOL and INT is defined and used for the programming.

Table 8.2.2 List of output variables

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 axis 4

Defining the variables in the PLC tags lists.

PLC tags

	Name	Tag table	Data type	Address	Retain	Visible...	Acces...	Comment
1	Tag_1	Default tag table	Int	%MW10		☑	☑	
2	btn1	Default tag table	Bool	%I0.0		☑	☑	
3	btn2	Default tag table	Bool	%I0.1		☑	☑	
4	out1	Default tag table	Bool	%Q8.0		☑	☑	
5	Aout1	Default tag table	Int	%QW320		☑	☑	
6	out2	Default tag table	Bool	%Q8.1		☑	☑	
7	Aout2	Default tag table	Int	%QW322		☑	☑	
8	btn3	Default tag table	Bool	%I0.2		☑	☑	
9	btn4	Default tag table	Bool	%I0.3		☑	☑	
10	btn5	Default tag table	Bool	%I0.4		☑	☑	
11	btn6	Default tag table	Bool	%I0.5		☑	☑	
12	btn7	Default tag table	Bool	%I0.6		☑	☑	
13	btn8	Default tag table	Bool	%I0.7		☑	☑	
14	Aout3	Default tag table	Int	%QW324		☑	☑	
15	Aout4	Default tag table	Int	%QW326		☑	☑	
16	out3	Default tag table	Bool	%Q8.2		☑	☑	
17	out4	Default tag table	Bool	%Q8.3		☑	☑	
18	btn9	Default tag table	Bool	%I1.0		☑	☑	
19	btn10	Default tag table	Bool	%I1.1		☑	☑	
20	btn11	Default tag table	Bool	%I1.2		☑	☑	
21	btn12	Default tag table	Bool	%I1.3		☑	☑	
22	out5	Default tag table	Bool	%Q9.0		☑	☑	
23	out6	Default tag table	Bool	%Q9.1		☑	☑	
24	out7	Default tag table	Bool	%Q9.2		☑	☑	
25	out8	Default tag table	Bool	%Q9.3		☑	☑	
26	Ain1	Default tag table	Int	%IW304		☑	☑	
27	Ain2	Default tag table	Int	%IW306		☑	☑	
28	Ain3	Default tag table	Int	%IW308		☑	☑	
29	Ain4	Default tag table	Int	%IW310		☑	☑	
30	Ain5	Default tag table	Int	%IW312		☑	☑	
31	Ain6	Default tag table	Int	%IW314		☑	☑	
32	<Add new>					☑	☑	

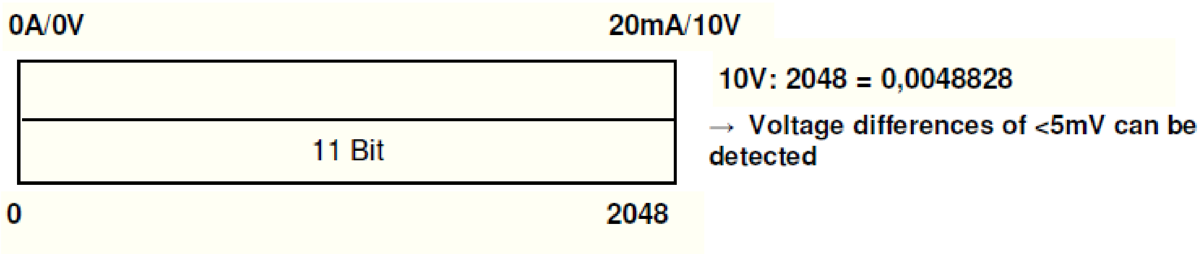
Figure 8.2.2 Window layout for defining the variables

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°C
- 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.

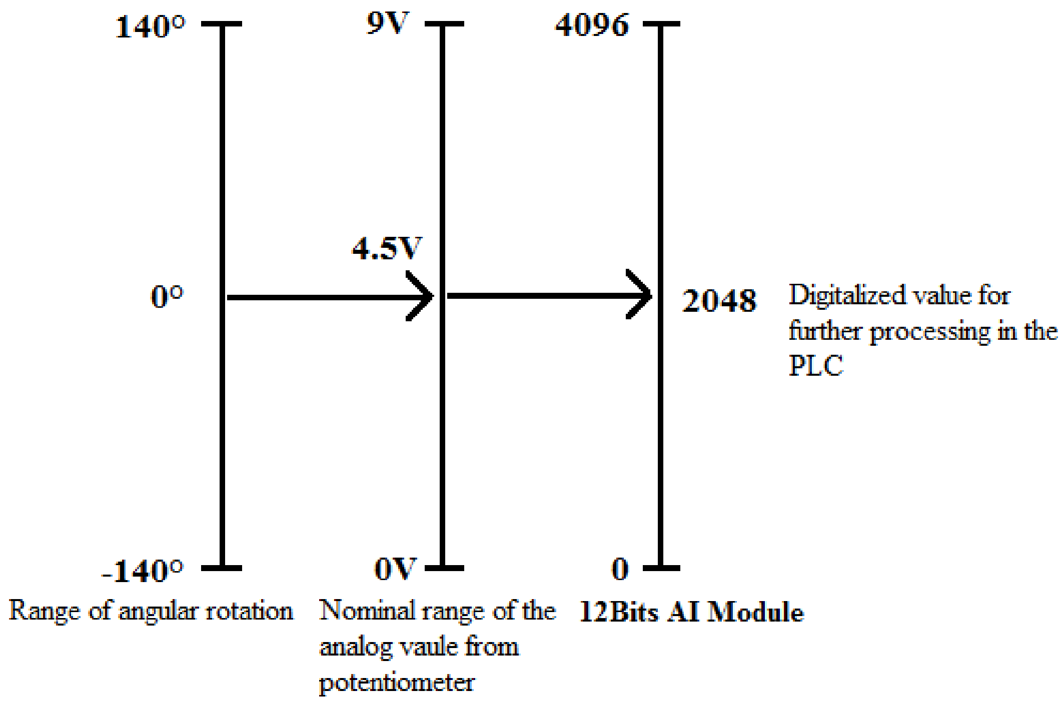


Figure 8.3 Diagram illustrate the conversion of angular value to the Int. value

The INT value for every axis is recorded using the online simulation. An axis 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 maximum and minimum rotation cannot be set in the program for these joints.

Table 8.3 The Integer (INT) values for the maximum and minimum rotation limits

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 of device configuration in the program, the measuring signal types and range can be set.

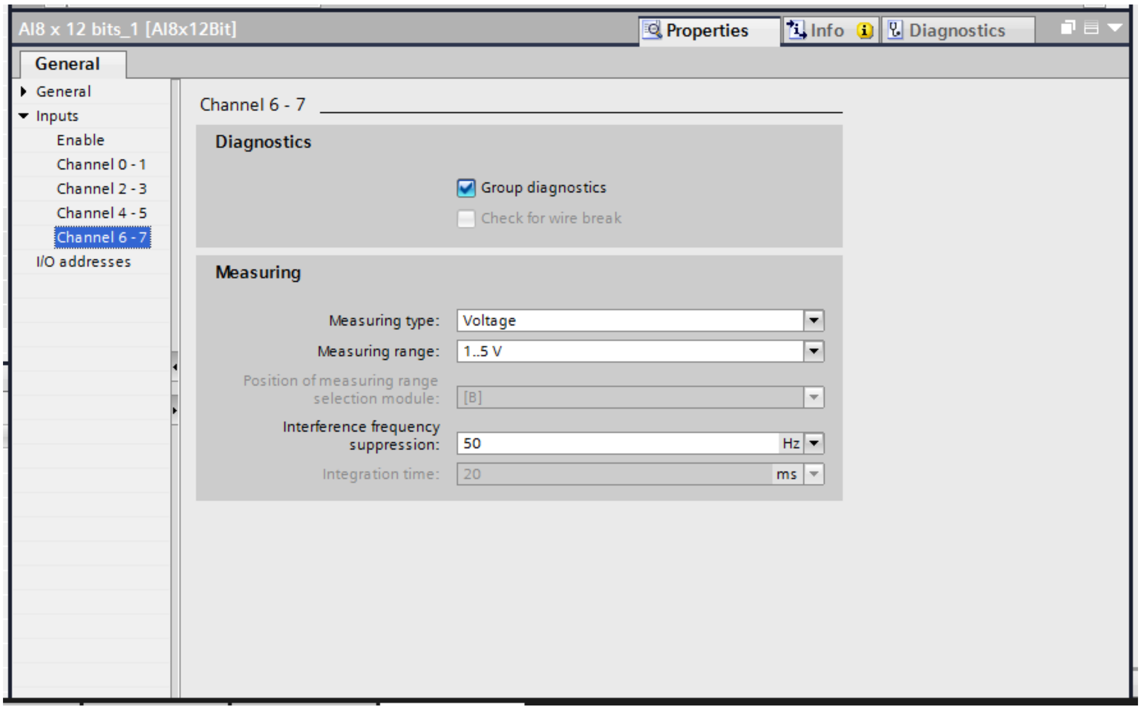


Figure 8.3.a. Analog Input channel setting (AI8x12bits)

For the analog output modules, the range of output is set to be ±10V.

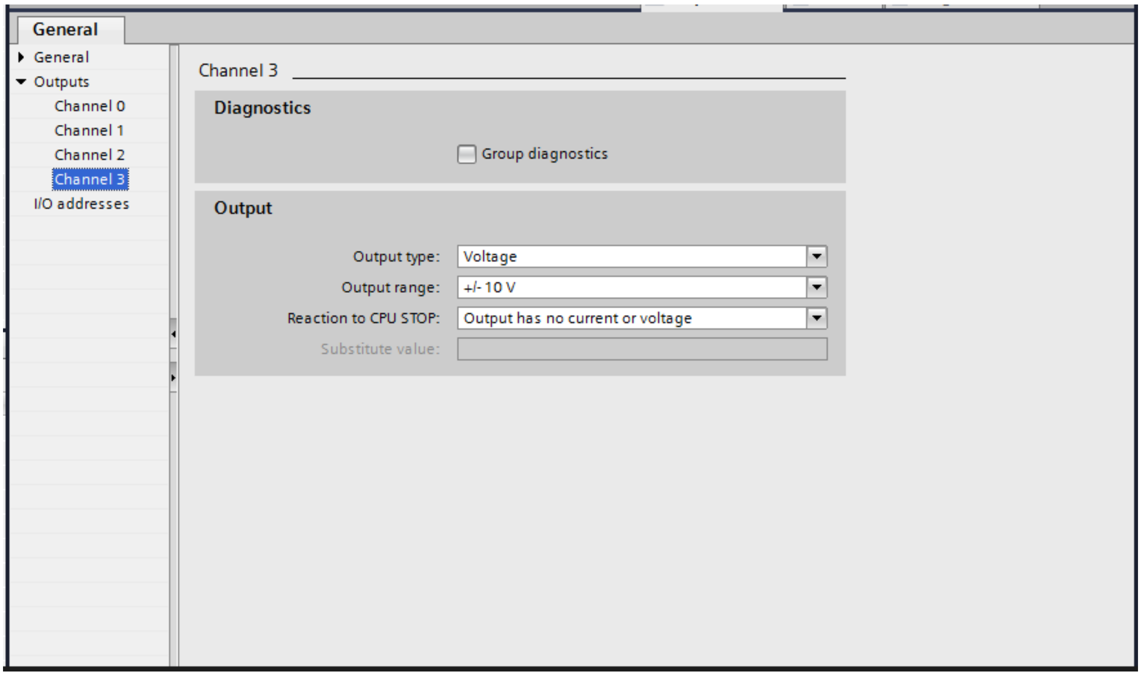
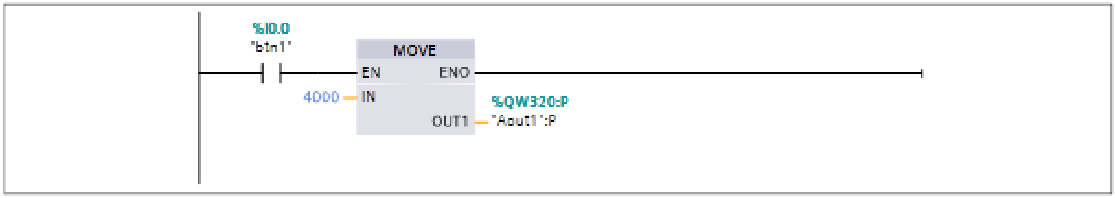


Figure 8.3.b Analog Output voltage setting.

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 is used to controlling 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 program for controlling the direction and limiting the speed of the motor can be show below.

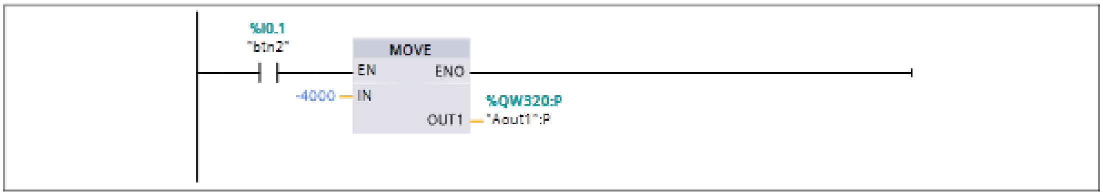
Network 1:



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

In this program, the analog output value for driving the motor axis in positive direction is 4000. When button 1+ is pressed, the axis1 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 enable the analog output INT value of -4000.

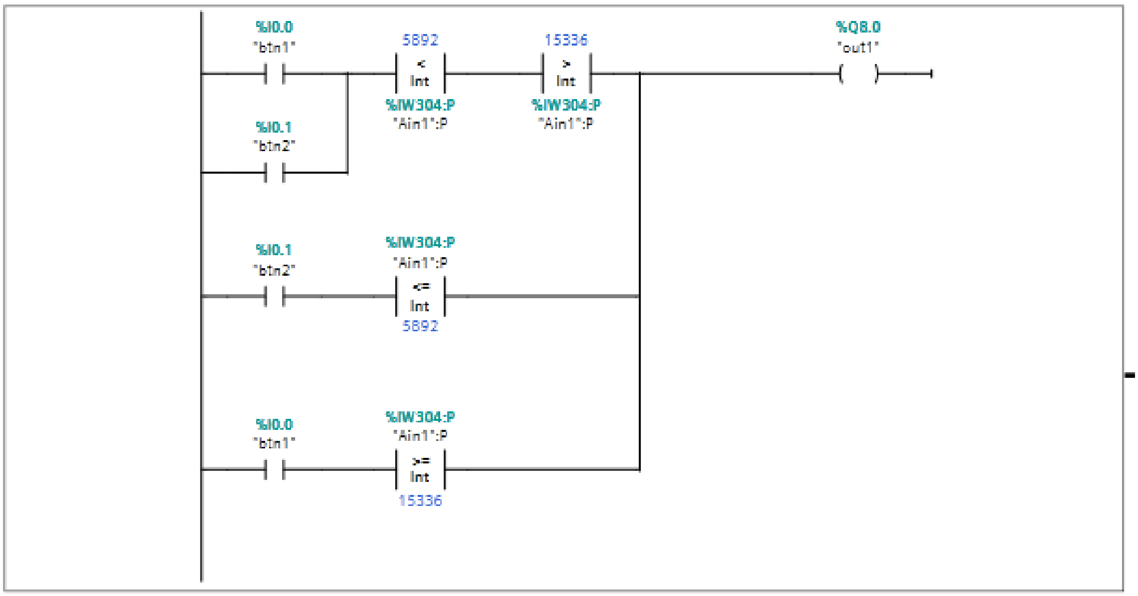
Network 2:



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

In a manual control system, the limit of the rotation of the 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 value are recorded as the rotation limits in two direction and maximum and minimum limits helps to protects the motor from the collision. The program written for limiting the rotation angle can be shown below

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	

The first four axes have the speed control during rotation but the remaining two does not have the rotation speed control system in it. It is because, there is 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 its 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 problems 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 for the test the programs and to arm performance during its operation, relay is used.

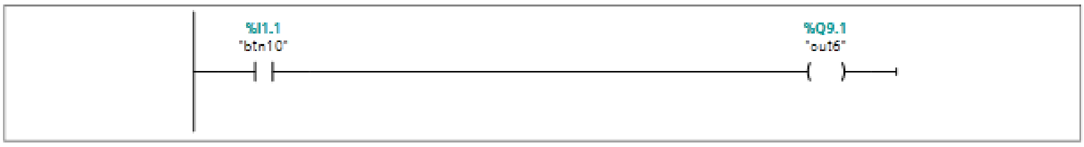
The positive and negative movement is control by the digital outputs. This digital output is connected to relay which act likes ON/OFF-switch for controlling the direction of the motor.

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	

For controlling the rotation limit, where relay is used, same types of program is used a above.

8.5 Automatic Movement

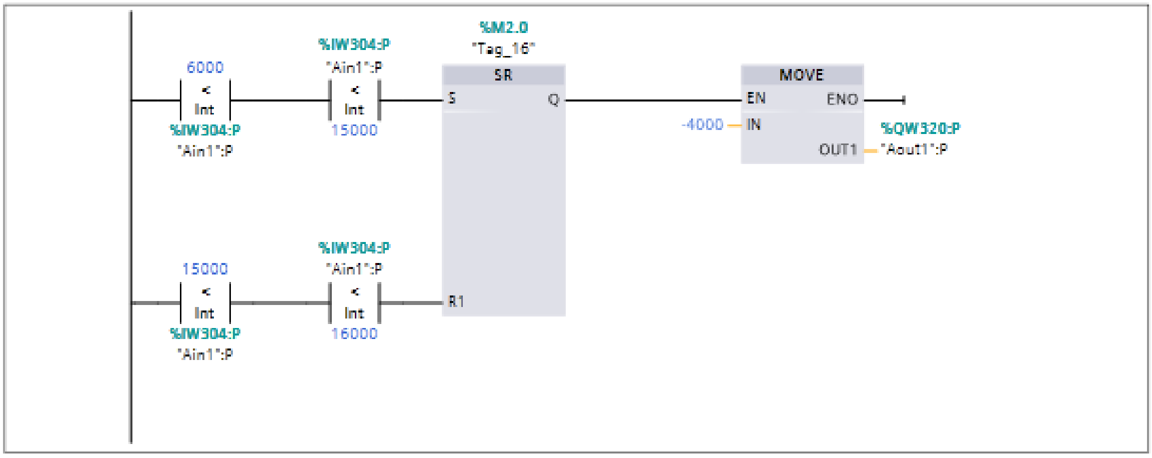
The programming for the automatic movement control system of the arm is done in such a way that it performs a sequence of task. The position and orientation of the arm can be determined by the INT value from the potentiometer, but the calculation is complex. The program is just the demonstration for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

Figure 8.5 Back and forth movement controlled by a range of INT value

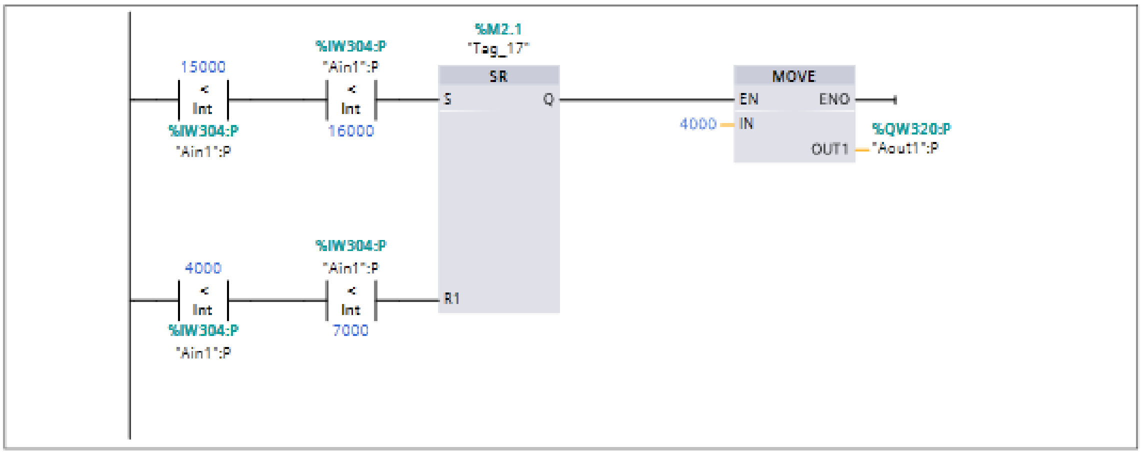
Program for controlling the forward movement.

Network 1:



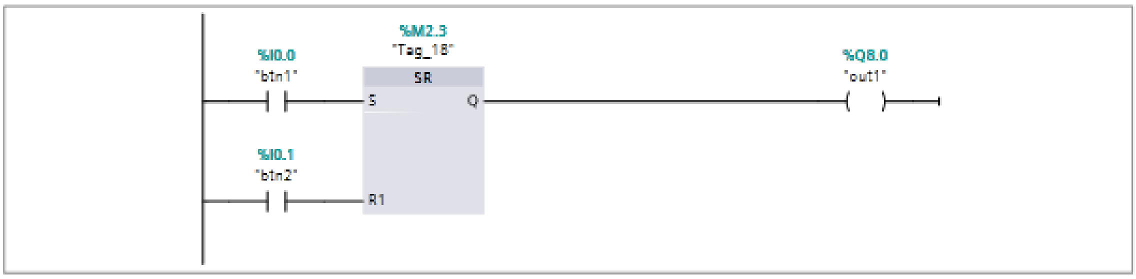
Program for controlling the backward movement.

Network 2:



The digital output works as ON/OFF switch for controlling the motor.

Network 3:

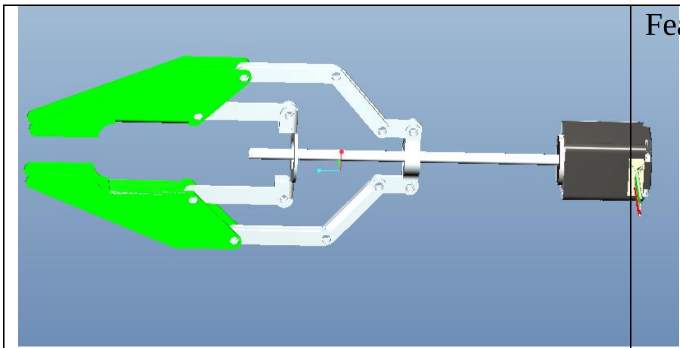


9 DESIGN AND CONSTRUCTION OF GRIPPER

This section includes the design and construction phase of the gripper. All the necessary design process for a complete product is includes in this parts. As compare to real design process in a real working life, this gripper design also includes all the essentials aspects of a product development.

9.1 Gripper Design

The following pictures show the mechanical grippers for a robotic arm. All of this 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 gripper is to make all the functions controlled by electricity. Using extra pneumatic or hydraulic system for 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 this gripper is made finalized

 **Figure 9.1.a Gripper option 1**	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.b Gripper option 2**	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

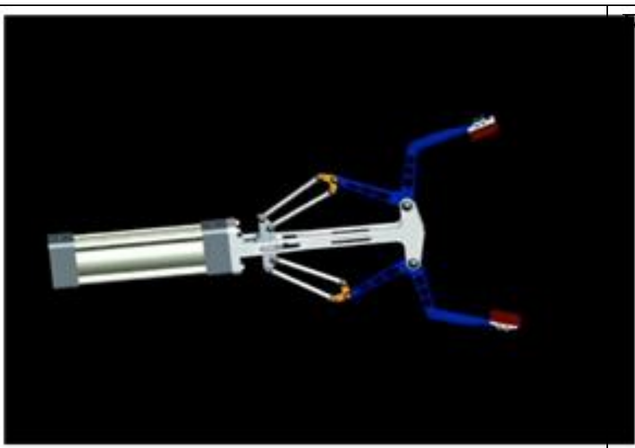


Figure 9.1.c Gripper option 3

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.d Gripper option 4

Features and Comments

- Its 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 individuals' grippers are taken in consideration. The selection is made among this gripper in such 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 picture shows the closing position of the gripper. The gripping action is flexible for any size of 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 128mm X 63mm

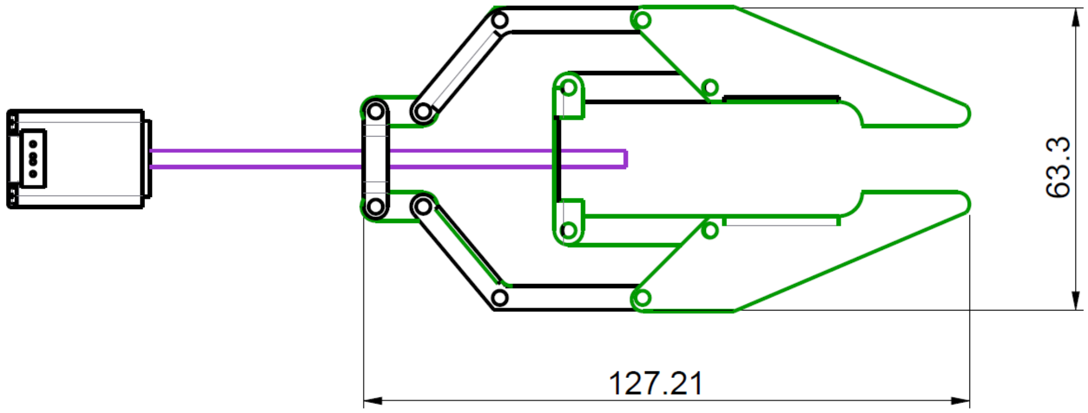


Figure 9.2.a Closing position of gripper

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

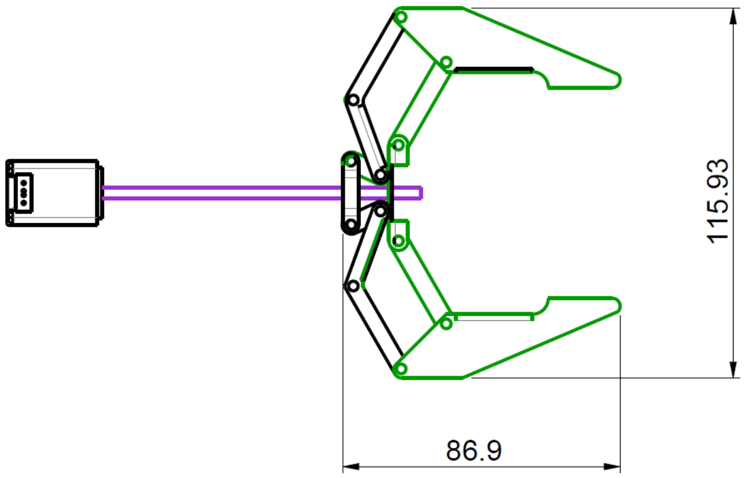


Figure 9.2.b Opening position gripper

This mechanical gripper is designed to works using a linear actuator and all the necessary studies and technical documentation is prepared for the manufacturing. Another options for the gripper is magnetic gripper. The magnetic gripper can be bought from the market and, simply assemble to the arm which save the time and the cost. But the lack of time and availability of the resources makes the construction of gripper to be terminated. It is decided not to use any kinds of gripper in this arm.

10 CONCLUSION

A control system for controlling the Robotic Arm manipulator was accomplished with successful demonstration and testing. At the beginning of the project, a solid plan for the project was made, but due to the circumstances and problems encounter, a frequent change is made in the plan. A detail studies was made to find the best possible solution for designing and constructing a control system, which includes selection of components like PLC, PLC's Components, gripper, motor controller, power supply units etc., and most of these components were available in the laboratory.

Most of the time of the project was spend for constructing the control components and its assembly, which is the main part of this project. For the gripper design, only the theoretical studies and required documentation was prepared. The wiring and installation of the component was done with the guidance of the supervisor. Some of the additional components like control pendent, integration circuit board, voltage regulator and support system was designed during the project.

The programming was done 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 demonstrated in the robotic arm. But, for the automatic modes, the programming done was basic with very few features due to lack of time, but this show 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 project was worthful with positive result. During this project, it encounters a number of problems regarding the technical difficulties, and some problems due to lack of understanding. This project teaches much about dealing with problem and finding the solution own self. The wiring and installation has a lot of work to be done in this project, which makes more skilful in using tools and equipment. The other thing, this project has completely different was the programming software "TIA Portal V11 Sematic". In control system course, there is less about PLC programming software, but this project helps to learn more about it. This project for designing 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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APPENDIX