Development of two-dimensional plotter using programmable logic controller and human machine interface

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Abstract. In this modern world, the use of computerized numerical control technology has become indispensable in the areas of logo designing, furniture, and marble industries, etc. It inspires authors to develop the two-dimensional Plotter device using Programmable Logic Controller (PLC) and Human Machine Interface (HMI) to reduce the complexity of CNC machines. The functional application of X-Y axis-based Plotter is used to draw a variety of shapes, text, and images on the solid surface. In this study, ladder programming is performed according to the script, and the program is thus executed by PLC which further gives the signal to the actuators. The X-Y axis is controlled by servo drivers which drive servo motors. DC motor is used to decide the position of the pen. Human Machine Interface (HMI) is used to provide supervisory control to the X-Y plotter. It has been achieved that the implementation of PLC-HMI based control panel gives comfortable and secure control. Thus, the desired text/shape is achieved with ease, when the motors move along concerning X-Y axis and subsequently pen touches the sheet to draw text/shape. Hence, it is stated that more real-world applications could also be achieved using the plotter device.

Keywords: Plotter; controller; machine; PLC; CNC.

1. Introduction
In this modern world, the use of technology in industries as well as in the education sector has become indispensable [1]. World wide application of computerized numerical control technology such as logo designing, furniture, and marble industries inspires to work on the development of a Plotter device. The plotter is a special kind of printing/sketching device that uses a pen to draw shapes, text, and images on sheets and solid surfaces [2]. Plotter provides a fast and efficient way to produce drawings or artwork [3]. X-Y plotter is a device that is used to operate in two axes of motion (‘X’ and ‘Y’) to draw shapes. The X-Y plotter system is very basic compared to conventional CNC systems as the programming is typical for 3 axes [4]. The idea of developing PLC-HMI based X-Y plotter comes from the revolutionary technology of CNC machines and advancement in the world of PLC controllers and their industrial reliability [5]. In a past study, a hybrid controller was developed using a low-cost microcontroller for making a position traveling system [6]. The X-Y plotter uses a pen to draw text or shapes on a sheet over a square organize framework. In further sub-section, complete detail of hardware and software parts has been discussed related to X-Y plotter device.
1.1 Hardware Part

The main hardware parts of this plotter are X-Y plotter table and the control panel [7]. On the control panel there is PLC, HMI, 2 servo drivers to drive 2 servo motors. The panel consists of LEDs to indicate the status of panel, toggle switches to change the direction of servo motors and to Start/Stop servo motor, and an emergency switch to cut off the supply in any emergency condition. Switches are connected to the input of PLC while LEDs are connected to the output of PLC which is connected to each other by programming language [7].

PLC- PLC is a solid-state device that receives the signal from user control devices such as sensors, push buttons and limit switches [8]. Process the signal according to the programming language and provides output for controlling the devices such as relays or motors. It can be programmed easily and can be used in a harsh environment and has a long life. It is easy to troubleshoot PLC and to modify PLC programs. Generally, PLC comes in two types: (a) Relay type which is used for on/off condition. It works slow and can switch a large current, work on both DC and AC and has a shorter lifetime. (b) Transistor type which is used with the devices which provide high pulse signals such as servo motors. It is fast, switches a small current, has a long lifetime, and works with DC only. So, the PLC of transistor type named as Fuji SPF-NA0PA24T-34C is used for this study. The main reason to use transistor type PLC is that this model allows using 2 servo motors flexibly by using PLS_PLS command. Figure 1 shows the FUJI PLC – SPF-24 input-output used for developing the plotter device. Human Machine Interface-Human Machine Interface (HMI) connects the machine to humans. Figure 2 represents the FUJI HMI - Monitouch 7 inches.

**Figure 1.** FUJI PLC – SPF-24 input-output (IO) [13].

**Figure 2.** FUJI HMI - Monitouch 7 inch [14].

HMI is an essential resource that can be used to review and monitor processes, visualize data, and diagnose problems in industrial organizations as well as other sectors also [9]. HMI communicates with PLC and input/output devices to get information on the screen. The information can be seen in the form of graphs and charts. The HMI which we are using is FUJI Monitouch T-Series 7-inch, colored HMI that gives supervisory control of plotter on the touch screen and is also used to check the status of input/output devices and can on/off the devices by simply touching the screen.

Servo Motor-A servo motor is a rotary actuator or motor that allows for precise control in terms of angular position, accelerations, and velocity capabilities that a regular motor does not have. A servo motor
is a linear or rotary actuator that provides fast precision position control for closed-loop position control applications. The Servo motor has a high-speed response due to low inertia. The servo works on a servo mechanism that uses position feedback to control the speed and final position of the motor. It uses an encoder or speed sensor to provide speed feedback and position [10]. Figure 3 shows the FUJI servo motor.

Servo Drive-Servo system consists of four main components: a motor, a drive, a controller, and a feedback device, which is typically an encoder [10]. The controller and drive work together to determine what the motor needs to do and send the necessary electrical energy to the motor to make it happen & servo drive can also be referred to as an amplifier to deliver a specific amount of voltage and current to the motor. Figure 4 shows the FUJI servo driver used.

![Figure 3. FUJI servo motor [13].](image1)

![Figure 4. FUJI servo driver [13].](image2)

The servo drive which we are using is Alpha 5 Smart servo drive. It has direction and pulse control to drive the servo motors.

1.2 Software Part

PLC Software- FUJI PLC communicates with SX Programmer Standard software which uses LADDER LOGIC as the programming language. It provides a user-friendly operating environment and has many programming instructions. Figure 5 represents the SX-Programmer Standard programming interface.

![Figure 5. SX-Programmer Standard programming interface.](image3)
To drive the servo motor, to change the direction of the motor, to count the pulses, to check the status we can use PLS_PLS COMMAND in PLC software as shown in Figure 6.

![Figure 6. SX-Programmer Standard – PLS_PLS command.](image)

HMI Software- Fuji Monitouch T-Series HMI communicates with V-SOFT software which is used to design screens. Figure 7 represents the V-Soft FUJI HMI Software.

![Figure 7. V-Soft FUJI HMI Software.](image)
A screen can be designed by using tags that acts as an interface between PLC and HMI. It is user-friendly software. This research paper includes the development of a simplified X-Y plotter which matches the industrial standards and also designing a control panel to control this plotter, panel consists of PLC-HMI controllers [11]. PLC is used to execute the program and HMI gives supervisory control of the plotter on the touch screen, also used to check the status of inputs/outputs. The implementation of PLC-HMI based control panel gives comfortable and secure control. It uses two servo motors to control X axis and Y axis and a DC motor to lift the pen. The drawing instruction is given to PLC by ladder programming. According to the program, actuators start changing position and the pen touches the sheet to draw text/shape. The proposed X-Y plotter can be used for PCB designing, logo designing, furniture industries, and marble industries.

2. Methodology

The ladder programming has been performed according to the script and then download the program to PLC from the laptop, with the programming cable. This program is executed by PLC and further signal passed to servo motors by servo driver as per the generalized instruction. Servo motor moves and also other output actuators. The axes of plotter X, Y and Z operate as follows: X servo motor which assists to move left and right, Y servo motor moves front and back, and Z axes DC motor lifts pen up and down as per program [5]. Further subsections have contained the detail about the system hardware specification and hardware architecture.

2.1 System Hardware Specification

The proposed plotter is the best example of mechatronics engineering field. It is a combination of hardware and software. Hardware is consisting of mechanical and electrical devices. Figure 8 shows the pictorial top view of X-Y plotter. Complete mechanical hardware and electrical specifications have been shown in Table 1 and Table 2, respectively.

| S.NO. | NAME OF EQUIPMENT   | SPECIFICATION                              | QUANTITY |
|-------|---------------------|---------------------------------------------|----------|
| 1.    | Plotter Base        | Mild Steel, 3mm sheet (1x1mtr.)             | 1        |
| 2.    | Ball Screw          | Nominal diameter: 16mm, length: 1 mtr., dynamic load: 680kgf | 1        |
| 3.    | Linear Guides       | 16mm                                        | 2        |
| 4.    | Mounting bracket    | Mild sheet                                  | 1        |
| 5.    | Ball Bearing        | 16 mm bore, chrome steel with rubber seal   | 1        |
| 6.    | Scale               | 1 mtr.                                      | 2        |
| 7.    | Coupling            | Gear type                                   | 2        |
2.2 System Hardware Architecture

PLC is the brain of the plotter and all the input and output devices are connected to it. The power flows to system through the main switch which is 230 VAC supply. Figure 9 depicts the block diagram of the system architecture and Table 3 shows the abbreviation of block diagram system architecture.

Figure 8. Pictorial top view of X-Y plotter device.

Figure 9. Depiction of the Block diagram of the system architecture.
Table 2. Describing the complete electrical hardware specification.

| S.N.o. | NAME OF EQUIPMENT                  | SPECIFICATION                                                                 | QUANTITY |
|-------|------------------------------------|-------------------------------------------------------------------------------|----------|
| 1     | PLC Fuji SPF -NA0PA24T-34C         | (24V DC power supply, 24V DC digital input 14 points (High-speed: 200kHz, 4 points; Medium-speed: 20kHz, 4 points; Medium-speed: 16.6kHz, 6 points;), Tr sink output 10 points (High-speed: 200kHz, 4 points; Medium-speed: 20kHz, 4 points), Detachable terminal block) | 1        |
| 2     | HMI FUJI Monitouch T series 7inch, colored |                                                                               | 1        |
| 3     | Servo Motor with Drive FUJI Servo system Alpha5 Smart (0.75KW) |                                                                               | 2        |
| 4     | DC Motor 12DC 300rpm               |                                                                               | 1        |
| 5     | Power Supply (SMPS) Input supply 230VAC to output 24VDC 5A |                                                                               | 1        |
| 6     | Relay Card 8 channel relay board module DC 24V 10A |                                                                               | 1        |
| 7     | DC to DC Converter 24DC to 12DC    |                                                                               | 1        |
| 8     | Sensors Inductive Proximity Sensor (18mm) |                                                                               | 4        |
| 9     | Limit Switches NO/NC SPDT front actuator without roller 6A 250VAC 100VDC |                                                                               | 4        |
| 10    | Switches 250VAC 3A SPST NO & NC Round Momentary Push Buttons |                                                                               | 6        |
| 11    | MCB DP -32 Amp                     |                                                                               | 1        |
| 12    | Emergency Switch Mushroom NC emergency stop self-locking push-button switch red 10A 660VAC 380VDC IP45 |                                                                               | 1        |
| 13    | Wires As per req.                  |                                                                               | As per req. |
| 14    | Programming/Communication Cables As per req. |                                                                               | As per req. |
Table 3. Abbreviation of block diagram system architecture.

| S.NO. | NAME OF EQUIPMENT   | Specification                                      | QUANTITY |
|-------|---------------------|----------------------------------------------------|----------|
| 1.    | Plotter Base        | Mild Steel, 3mm sheet (1x1mtr.)                    | 1        |
| 2.    | Ball Screw          | Nominal diameter: 16mm, length: 1 mtr., dynamic load: 680kgf | 1        |
| 3.    | Linear Guides       | 16mm                                               | 2        |
| 4.    | Mounting bracket    | Mild sheet                                         | 1        |
| 5.    | Ball Bearing        | 16 mm bore, chrome steel with rubber seal          | 1        |
| 6.    | Scale               | 1 mtr.                                             | 2        |
| 7.    | Coupling            | Gear type                                          | 2        |

The 230VAC supply is then converted to 24VDC using SMPS, to power up PLC, HMI. Switches are connected to the input card of plc to start-stop and direction operation of the actuator according to logic stored. Sensor and limit switches are connected to PLC input card to provide a safety signal to PLC controller. Both servo motors are directly connected to the output card of PLC [12]. The Servo motor needs a power supply which is directly given from the main switch. The control signal is high-speed pulse output for position and speed control of servo motor which is given by transistor type plc. Table 3 shows the abbreviation used in system architecture (Figure 9).

Servo Motor 1 is coupled to ball screw which is moving in left-right direction and Servo motor 2 is coupled to ball screw which is moving in front-back direction. DC motor operates on 12VDC which is given to DC to DC converter to relay board and relay board is connected to plc output. DC motor is used to lift the pen up-down. PLC is interfaced with HMI via Rs 232 Communication protocol. HMI is used to control and monitor the plotter system.

Finally, the X-Y plotter device is ready to create various shapes, blocks, or text. For this study, a phrase i.e. ‘CHITKARA UNIVERSITY PUNJAB’ has been draw. Figure 10 shows the real-time working picture of the plotter and pen arrangement.

![Figure 10. Real-Time working picture of plotter and pen arrangement.](image-url)
3. Complete working and Result analysis

3.1 Working of Plotter Device

X-Y plotter uses a FUJI SPF 24 IO T PLC and HMI and 24VDC power supply. The output of PLC is connected to the servo drivers. Servo driver is used to running servo motors which are used to drive X-Y axes. The Input of PLC is connected to sensors and limit switches which are used to define the end limit of both the axes. Figure 11 illustrates the flow chart that described the plotter operating procedure. Sensors are also used to set the home position while drawing. Programming of desired shape or text is written in ladder logic by the programmer in SX-Programmer Standard. The program is downloaded in PLC using the SX-programmer standard. PLC can receive input control signals through physical switches or HMI. On pressing the START button plotter comes into run mode and the plotter starts drawing. The motion of both X-Y axes starts in synchronization according to logic in the program. If there may any error or unavoidable situation direct way, need to press the emergency switch which able to cease the whole process. Figure 12 shows picture of the human-machine interface (HMI) control screen.

![Flow chart of Plotter operating procedure](image)

**Figure 11.** Flow chart of Plotter operating procedure.
3.2 Steps followed for Programming code behind Plotter operation

The major steps of programming code for operating the X-Y axis plotter device has been discussed in detail as:

- Servo motors require pulse input from the controller for its accurate movement. Here, two servo motors have been utilized for X and Y axis, respectively.
- Both the motors provided control signal for Fuji SPF 24I/O Transistor type PLC. This PLC can control 2 Axis Motion.
- In the programming of PLC, an inbuilt PLS_PLS function block has been considered.
- This Block provides enable, pause, position, direction, frequency, count, action, error, and status control. Figure 13 (a) and Figure 13 (b) represent the block diagram for both X and Y-axis along with the memory bits and data registers assigned.
- Further, various safety interlocks using limit switches and inductive proximity sensors have been provided, to ensure accident-free operation of the machine. Figure 14 represents the ladder logic of safety interlocks.
- The entire system can be controlled via hardwired push buttons and HMI. All the standards have been adopted in panel designing and wiring methodology. The emergency stop is provided to terminate all the processes as and when required.
- The complete system’s working is divided into two sub-processes i.e. (a) Manual mode and (b) Pre-programmed mode.

![HMI control screen.](image)

**Figure 12.** HMI control screen.
3.2.1 Manual Mode
Points followed regarding system’s working in manual mode as:
- Manual mode provides the user full access to control X and Y axis position and status of the pen.
- Physical buttons and graphical control via HMI are also provided.
- Positional feedback is also displayed to the user for enhancing future movements.

3.2.2 Pre-programmed/Automatic Mode
The major points followed for the system’s working in Pre-programmed/Automatic mode are:
- In this mode, the script of the required text is constructed in the form of ladder logic.
- Calculations provide the data that pulse count of “2047” provides a movement of 1cm.
- The alphabet or the numeric text is then divided into various horizontal, vertical, or diagonal movements.
- Each directional movement is attached via moving (x*2047) pulses to the assigned data registers. Figure 15 depicts the ladder logic using various commands such as move, timer, and set-reset commands.
- These methods can write the script in different sizes (length*breadth) such as 4*4 cm², 4*5 cm², 5*5 cm² and 3*4 cm².
- Further, the finalized code can be initiated via start push button and the same can be terminated via stop button.
- Lastly, after adopting the program, “CHITKARA UNIVERSITY PUNJAB” has been drawn on a required solid surface.

**Figure 13 (a).** Representation of functional block for the PLS_PLS command for X-axis.  
**Figure 13 (b).** Representation of functional block for the PLS_PLS command for Y-axis.
Figure 14. Illustration of the ladder logic of the safety interlocks.

Figure 15. Depict of ladder logic using various commands (move, timer, and set-reset commands).

Figure 16 represents the final Plotter Two dimensional (X-Y) experimental arrangement with mechanical and electrical attachment.
Figure 16. Final Plotter Two dimensional (X-Y) experimental arrangement with mechanical and electrical attachment.

The X-Y Plotter is developed to draw text using PLC, HMI, Servo motors, and servo drivers with sketch pen mechanism. After the successful configuration of different components, the final result is shown in Figure 17. It is cleared that the drawn text phrase ‘CHITKARA UNIVERSITY PUNJAB’ has been formed with higher accuracy due to feedback provided by servo motors.

Figure 17. The output of plotter with a sketch pen.

Hence, it is stated that the 2-D plotter device is innovative and could be used further for more real-world applications related to texting, drawing, and making various shapes.

4. Conclusion
This study is concentrated on the development of X-Y plotter using a Programmable Logic Controller (PLC) and Human Machine Interface (HMI) which can draw text/shapes on a given solid sheet. It works with higher accuracy due to feedback provided by servo motors. The servo drivers used also provides precise control of servo motors. Transistor type PLC provides high-speed pulses to drive servo motors. HMI used provides easy access to the system, secure control, and also saves time. Software used is open software and user friendly. The position, direction, frequency, pulse count, and status of servo motors can be easily determined using PLS-PLS command in the programming software. This is a low-cost project as compared to the other CNC machines. The designed system is user-friendly and can be used for more real-world applications related to texting, drawing, and making various shapes.
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