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Design an Industrial Robot Arm Controller Based on PLC

Abstract. *This paper aims to design and implement a practical realization of a robot arm controller system. The robot arm consists of multiple stepper motors controlled by a Programmable Logic Controller (PLC). Three types of stepping excitation methods are employed, which are: One-phase ON, two-phase ON, and One-two-phase ON for operating the stepper motors. The angular displacement, angular velocity, and direction (Bi-directional) of stepper motors are handled in each of these methods. Siemens LOGO! 8 24 CE has been utilized in this work. The Function Block Diagram language is used to realise the proposed PLC controller system via the software environment program "LOGO! Soft Comfort Version 8.2". The direction statements and the values of the angular displacement and angular velocity of each motor used in the robot arm are computed and displayed locally on the digital display unit of the PLC. Additionally, an integrated web server that facilitates remote monitoring on a smartphone, which requires a LOGO!-router connection. This paper emphasizes the ease with which stepper motors can be controlled using any type of stepping excitation method based on a PLC. Using the PLC saves electronic components used in the drive circuit because low requirement of interface circuit linking the PLC and the stepper motor is used, lowering the cost and increasing the controller's overall reliability.*

Streszczenie. *Celem artykułu jest zaprojektowanie i wdrożenie praktycznej realizacji układu sterowania ramieniem robota. Ramię robota składa się z wielu silników krokowych sterowanych przez programowalny sterownik logiczny (PLC). Stosowane są trzy rodzaje metod wzbudzania krokowego, którymi są: jednofazowe włączone, dwufazowe włączone i jedno-dwufazowe włączone do obsługi silników krokowych. Przemieszczenie kątowe, prędkość kątowa i kierunek (dwukierunkowy) silników krokowych są obsługiwane w każdej z tych metod. LOGO Siemensa! 8 24 CE został wykorzystany w tej pracy. Język Diagram blokowy funkcji jest używany do realizacji proponowanego systemu sterownika PLC za pośrednictwem programu środowiskowego „LOGO! Soft Comfort wersja 8.2". Instrukcje kierunku oraz wartości przemieszczenia kątowego i prędkości kątowej każdego silnika używanego w ramieniu robota są obliczane i wyświetlane lokalnie na cyfrowym wyświetlaczu sterownika PLC. Dodatkowo zintegrowany serwer WWW, który umożliwia zdalne monitorowanie na smartfonie, co wymaga połączenia z routerem LOGO!. Ten artykuł podkreśla łatwość, z jaką można sterować silnikami krokowymi przy użyciu dowolnej metody wzbudzania krokowego opartej na sterowniku PLC. Korzystanie z PLC pozwala zaoszczędzić elementy elektroniczne używane w obwodzie napędowym, ponieważ niskie wymagania dotyczące obwodu interfejsu łączącego PLC i silnik krokowy są używane, co obniża koszty i zwiększa ogólną niezawodność sterownika.* (***Projekt kontrolera ramienia robota przemysłowego oparty oPLC***)

Keywords: PLC, Function Block Diagram, Stepping Excitation Method, and Robot Arm.
Słowa kluczowe:.Robot przemysłowy, kontroler, PLC

Introduction

All One of the most used terms in industrial automation is "robot arm." Selecting a proper controller device and managing the system dynamics are two of the most difficult aspects of developing a robot arm [1]. Several authors have described the construction of a robotic arm and how to control it with various controllers. The following are the details of the literature review which is relevant to this work: The authors of [2] designed and tested a serial port interface circuit for programmable control of multiple permanent magnet unipolar stepper motors to be operated on a biped robot with ten degrees of freedom, five on each leg. The authors of [3] propose a parallel port interface circuit for controlling several stepper motors which are used in a robotic manipulator arm and a linear position table. The authors of [4] describe a control system for stepping motors using the AT89C51 microprocessor. The authors of [5] give an overview of open-loop stepper motor control with a CPLD and a mobile remote control device. The authors of [6] created an FPGA-based stepper motor subdivision control circuit. The authors of [7] designed a three-axis cutting machine by using PLC (Mitsubishi type), which provides excellent precision and accuracy in cutting objects compared to the manual cutting machine. The authors of [8] described how they generate pulses with a suitable frequency for driving the stepper motor by developing a prototype stepper motor controller system utilizing PLC. The authors of [1] A three-axis robot using a stepper motor with a micro-stepping excitation technique and closed-loop control is proposed and practically applied to realize accurate positioning, smooth movement, and high torque using an Arduino microcontroller. The authors of [9] proposed building a pick and place robot arm vehicle that could be controlled based on a android application. The Android phone and the Raspberry PI board are related to one another so that their development can be controlled. The authors of [10] designed an electro-pneumatic controlled colour selector robot arm. PLC S7 1200.The authors of [11] presented the design and implementation of artificial intelligence algorithms for manipulator hardware platform control utilizing a PLC. The advantages of PLC over other controllers are that they are resistant to the vibrations, shocks, high temperatures, and electrical noise that manufacturing equipment is subjected to; they also have high reliability, program flexibility, and strong adaptability for all kinds of harsh environments [12, 13]. With the motivation of the above literature review, the novelty of this paper is that a low-cost robot arm controller based on PLC has been designed and theoretically analysed.

Stepping excitation methods of stepper motor

A unipolar stepper motor can be excited in three different ways. The step sequence of the train pulses which are applied to the stepper motor's windings determines the mode of operation [14, 15, and 16]. These are the following:

One-phase ON stepping excitation method

Only one coil of winding is energized in this approach, as seen in table (1). This mode of operation is also known as the "Wave stepping excitation method". The motor will turn in a clockwise (CW) direction when energised with the following step sequence: Q1-Q2-Q3-Q4 as illustrated in table (1-a). Swapping the order of steps in the sequence from step 4 to step 1 (Q4-Q3-Q2-Q1) causes the motor to turn in a counter clockwise (CCW) direction as illustrated in table (1-b) [17, 18].

Table 1 Sequence of One-phase ON stepping excitation method: (a) CW, (b) CCW

a- CW

Step.	ϕ1	ϕ2	ϕ3	ϕ4
1.	ON	OFF	OFF	OFF
2.	OFF	ON	OFF	OFF
3.	OFF	OFF	ON	OFF
4.	OFF	OFF	OFF	ON

b- CCW

Step.	ϕ1	ϕ2	ϕ3	ϕ4
1.	OFF	OFF	OFF	ON
2.	OFF	OFF	ON	OFF
3.	OFF	ON	OFF	OFF
4.	ON	OFF	OFF	OFF

Two-phase ON stepping excitation method

As demonstrated in the table, the double coils of stepper motor windings are activated instantly in this manner (2-a). This mode is also called the "Full stepping excitation method". This approach achieves a complete natural stage revolution, hence the name, two-phase ON stepping excitation method. The polarity of the input winding is inverted each time a different step is triggered, resulting in a full rated torque [14, 15]. Reversing the order, as in the preceding mode, leads it to turn CCW, as shown in table (2-b) [16].

Table 2 Sequence of two-phase ON stepping excitation method: (a) CW, (b) CCW

a- CW

Step.	ϕ1	ϕ2	ϕ3	ϕ4
1.	ON	OFF	OFF	ON
2.	ON	ON	OFF	OFF
3.	OFF	ON	ON	OFF
4.	OFF	OFF	ON	ON

b- CCW

Step.	ϕ1	ϕ2	ϕ3	ϕ4
1.	OFF	OFF	ON	ON
2.	OFF	ON	ON	OFF
3.	ON	ON	OFF	OFF
4.	ON	OFF	OFF	ON

Table 3 Sequence of One-two-phase ON stepping excitation method : (a) CW, (b) CCW

a- CW

Step.	ϕ1	ϕ2	ϕ3	ϕ4
1.	ON	OFF	OFF	ON
2.	ON	OFF	OFF	OFF
3.	ON	ON	OFF	OFF
4.	OFF	ON	OFF	OFF
5.	OFF	ON	ON	OFF
6.	OFF	OFF	ON	OFF
7.	OFF	OFF	ON	ON
8.	OFF	OFF	OFF	ON

b- CCW

Step.	ϕ1	ϕ2	ϕ3	ϕ4
1.	OFF	OFF	OFF	ON
2.	OFF	OFF	ON	ON
3.	OFF	OFF	ON	OFF
4.	OFF	ON	ON	OFF
5.	OFF	ON	OFF	OFF
6.	ON	ON	OFF	OFF
7.	ON	OFF	OFF	OFF
8.	ON	OFF	OFF	ON

One-two-phase On stepping excitation method

This method combines the two preceding methods. With this form of excitation, the step angle of the stepper motor is reduced to half that of the full mode. Thus, this mode is also called the "Half stepping excitation method", resulting in increased resolution. The number of steps in this sequence is doubled compared to the provirus stepping excitation method. The arrangement of step-wise excitation of the windings in bi-directions is shown in table 3 [14].

Hardware Configuration

Siemens LOGO! 24 CE (0BA8 version) is utilized in the work. The outputs of the PLC LOGO! 24 CE (Q1 to Q4 are Normally Open (NO) relay contacts) drive the first stepper motor coils (ϕ11 to ϕ14 respectively) as shown in the circuit diagram in Fig. 1. The outputs of the first LOGO! DM8 24 (Q5 to Q8 also NO relay contacts) are utilized for driving the 2nd stepper motor coils (ϕ21 to ϕ24) respectively, and so on for the 3rd motor.

The technical parameters of the first stepper motor (Base motor) that was employed experimentally are: STP-43D1014-01 type, Unipolar sort, coil type: Hybrid, 1.8° step angle, 3.9 V rated voltage, 610 mA rated current. Whereas the second and third motors are symmetrical motors:

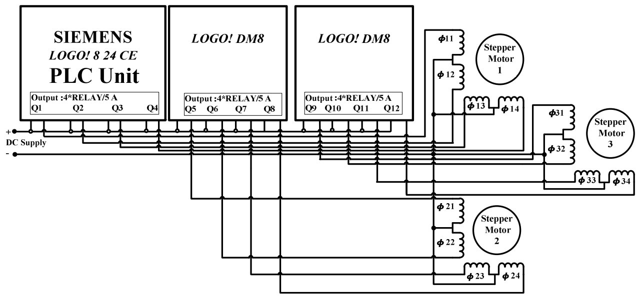


Fig. 1. PLC based stepper motors control connection diagram

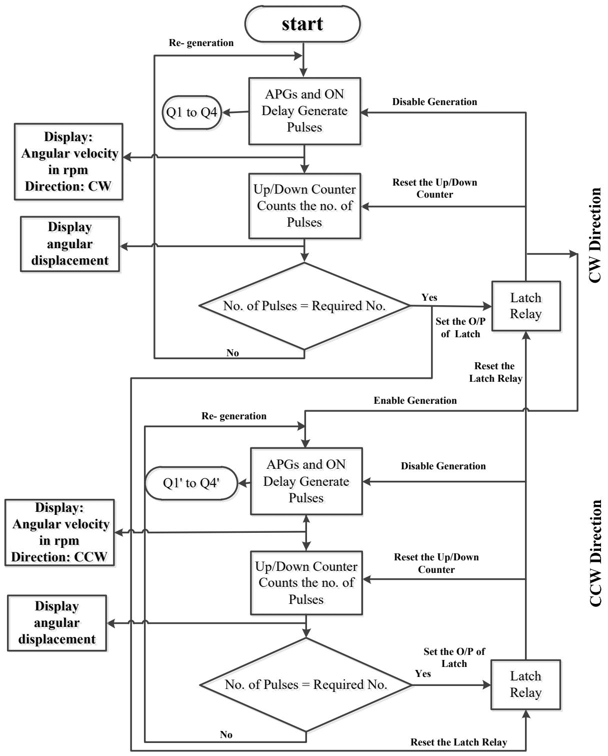


Fig. 2. Flowchart of the proposed work

V Proposed PLC Program Algorithms:

The stepper motors were driven using three different stepping excitation methods (One-phase ON, Two-phase

ON, and One-two-phase On). The Function Block Diagram language is used to design the PLC program structures, which will be explained in depth later. The proposed Function Block Diagram program was designed using the "LOGO! Soft Comfort V8.2" software programming package. The graphic in Fig. 2 depicts the general structure of the suggested programs for one of the stepper motors.

Implementation of One-phase ON stepping excitation method: (Wave)

The Function Block Diagram control program of the stepper motors using the One-phase ON stepping excitation method is shown in Fig. 3 (first stepper motor).

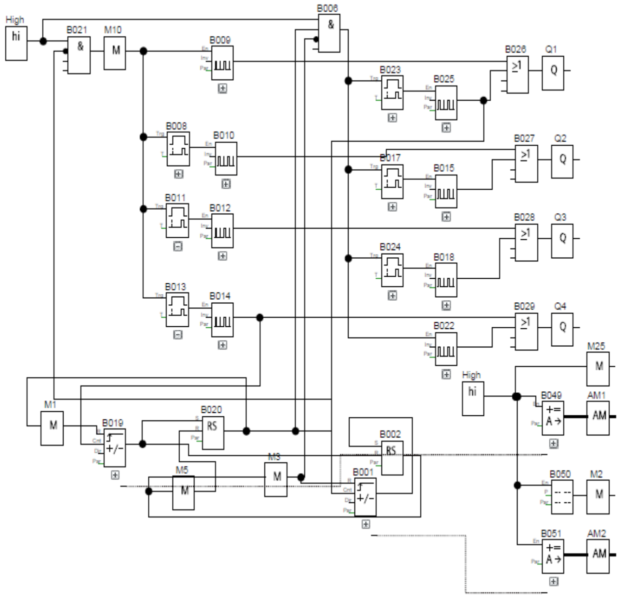


Fig. 3. Control program for the stepper motors using One-phase ON stepping excitation method

The proposed software is made up of a number of fundamental electronic logic devices that are controlled by the subsequent:

- Switch (Sw1) on the I/p Module (I1) of the LOGO! is employed to start the proposed controller program.
- Four of Asynchronous Pulse Generator Units are employed for generating the necessary pulses (Pulse Train Output PTO) for the phases of stepper motor in both directions (B009-B010-B012-B014 for CW direction and B025-B015-B018-B022 for CCW direction and).
- The stepper motor speed is adapted by modifying its parameters of the Asynchronous Pulse Generator unit (configurable ON/OFF ratio) by adjusting the pulse width: ON time and the OFF time.
- Accordingly, the first stepper motor will revolve a full cycle (360° in 200 steps) in the CW direction at a speed of 10 steps/sec (according to equation (1)) and then revolve the next cycle in the CCW direction at a speed that varies from the first direction (at 20 steps/sec).

$$\omega = \frac{step\ per\ second * 60}{step\ per\ revolution} rpm \quad (1)$$

Where ω is the angular velocity.

Three On-Delay units (B008-B011-B013) are employed to delay the starting signal that comes from I1 to the Asynchronous Pulse Generator-units of phase ϕ2, ϕ3 and ϕ4. So these units are used for adjusting the sequence of operating the stepper motor coils in each direction as shown in table 1.

- According to equation 2, the angular displacement (ϑ) of the stepper motor is exactly proportional to the both of number of pulses delivered to the motor and the step angle (φ).

$$\vartheta = p * \varphi \quad (2)$$

where p is the number of poles.

- Mathematic instruction units (B049- B051) are employed for calculating the instantaneous angular displacement for both directions according equation (1).
- To count the number of pulses that are produced by the Asynchronous Pulse Generator-unit, two UP/DOWN counter units (B019-B001) are employed; one for each direction according to equation (3):

$$No.\ of\ pulses = p * No.\ of\ counter\ counts \quad (3)$$

- The stepper motor that is used in this work has four phases with a 1.8° step angle, so for completing one cycle (i.e. 360°), the threshold number of the UP/DOWN counter count should equal 50, so that: .
- Latching Relay (RS) units (B020-B002) are used for resetting the UP/Down counters after it completes its On-threshold value for ending the current direction and initiating the second direction.
- Four OR gates (B003 - B004 - B005- B007) are utilized to deliver the produced signals for CW and the CCW direction to the output modules of LOGO! (Q1 to Q4).
- The outputs of the LOGO! are triggered in the following sequence [Q1-Q2-Q3-Q4] (see table 1-a) during CW movement. While in the CCW movement, these outputs are activated in reverse order [Q4-Q3-Q2-Q1]. These sequences of operations are repeated periodically in each direction in the same sequence, Q1 to Q4 or Q4 to Q1.
- It's easy to modify the parameters of the program to adjust the requirements of the stepper motor controller (speed, direction, and number of rotations).

Implementation of Two-phase ON stepping excitation method: (Full)

The Function Block Diagram program of this method identical to the Function Block Diagram code of the One-phase ON stepping excitation method, with the following exceptions:

- The o/p modules will be triggered in the following order when the motor revolves in the CW direction: [Q4 & Q1, then Q1 & Q2, then Q2 & Q3, then Q3 & Q4] according to table (2-a). This sequence will be repeated on a regular basis.
- The first Asynchronous Pulse Generator-unit (B009) produces ϕ1 with 0.04 sec ON: 0.04 sec OFF.
- After the delay time produced by On-Delay (B008) equals 0.02 sec, the second Asynchronous Pulse Generator -unit (B010) creates ϕ2 with 0.04 sec ON: 0.04 sec OFF.
- NOT Gates (B011, and B012) are used to invert ϕ1 to produce ϕ3, and invert ϕ2 to produce ϕ4 respectively.
- The operating pulses for a CCW direction are produced in the same approach as the CW direction, except the sequence differs: [Q4 & Q3, then Q3 & Q2, then Q2 & Q1, then Q1 & Q4] according to table (2-b).

Implementation of One-two-phase ON stepping excitation method: (Half)

The Function Block Diagram program of One-two-phase ON stepping excitation method is also similar to the Function Block Diagram program of the one-phase ON stepping excitation method, except several modifications :

- For CW direction, the output relays of the LOGO! PLC activated in the following series [Q1 & Q4 then Q1 then Q1

& Q2 then Q2 then Q2 & Q3 then Q3 then Q3 & Q4 then Q4] according to table (3-a).

- The first Asynchronous Pulse Generator -unit (B024) generates ϕ1 with 0.03 sec ON: 0.05 sec OFF. The second Asynchronous Pulse Generator -unit (B027) generates ϕ2 with 0.03 sec ON: 0.05 sec OFF but after delay time produced by On-Delay (B055) equals 0.01 sec. The third Asynchronous Pulse Generator-unit (B028) generates ϕ3 with 0.015 sec ON: 0.025 sec OFF but after delay time produced by On-Delay (BO22) equal to 0.01 sec. ϕ4 is produced by an On-Delay, Asynchronous Pulse Generator -unit, and Not gate.
- In the CCW direction, the first groups (Asynchronous Pulse Generator-unit and On-Delay) activate as in the CW direction, except the sequence differs: [Q4 then Q4 & Q3 then Q3 then Q3 & Q2 then Q2 then Q2 & Q1 then Q1 then Q1 & Q4] notice table (3-b).

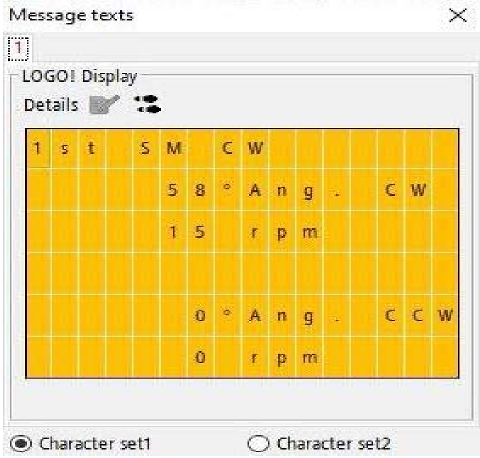
Experimental Results

To ensure the program in the LOGO! Soft Comfort is fully functioning and optimized, ready for download, the proposed programs were simulated via "LOGO! Soft Comfort/Simulation Mod." The communication processor is based on the Ethernet interface used in this work that facilitates wireless programming of the PLC. Fig. 4 presents the experimental prototype of the robot arm controller system.

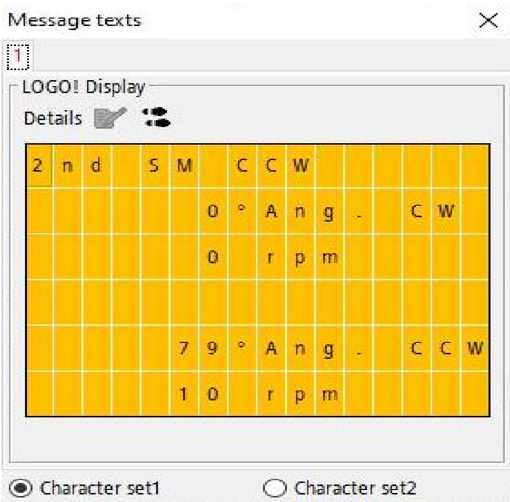
Fig. 4. Experimental prototype of the system

The "Message Text block" displays the message texts and the selected parameters of other blocks on the PLC-on-board display unit when the PLC is in RUN mode. The message text block "B050" is used to display the controller parameters for each stepper parameter involved: the direction of revolution of the motor (CW, or CCW), instantaneous angular displacement, and angular velocity at each direction of revolution, as shown in Fig. 5 (a), which is the first stepper motor (1st SM) of the robot arm in the CW direction at 15 rpm and 58 degrees of angular displacement. The message texts of the robot arm's second stepper motor (2nd SM) are shown in Fig. 5 (b). It revolves in a CCW direction at 10 rpm speed and 79 degrees of angular displacement.

The same data for a message text shown in the PLC display unit simultaneously appears on the smartphone. Just enter the IP address of the controller into the browser. As shown in Fig. 6, Fig. 6 (a) presents the data of the first stepper motor of the robot arm in the CCW direction at 10 rpm and 281 degrees of angular displacement. Figure 6 (b) depicts the data from the robot arm's second stepper motor. It revolves in a CCW direction at 10 rpm speed and 353 degrees of angular displacement



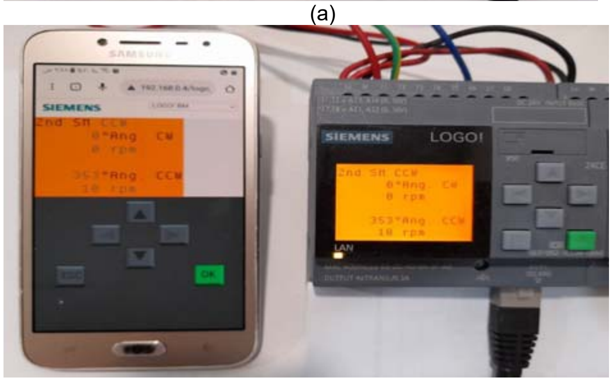
(a)



(b)

Fig. 5. Message texts

(a)



(b)

Fig. 6. Message texts are displayed on both the PLC display unit and smart phone.

The device utilization summary (shown in table 4) of the proposed architectures shows that controlling the robot arm is achieved by the small size of the available area (memory) of the PLC and the small number of resources. As a result, the design can be improved and other resources for closed loop control can be used.

Table 4: Device utilization summary of LOGO! 8 PLC

Resources	Used	Total
Function Blocks	51	200
Digital Inputs	1	24
Digital Outputs	12	16
Flag	10	27
Analog Inputs	0	8
Text Box	1	50
Text contents	1	50
Analog outputs	0	2
Program memory	608	3800
Block names	0	100
Analog flags	2	6
Cursor keys	0	4
Shift register	0	1
Shift register bits	0	8
Open connectors	0	16

Smooth and soft revolution of stepper motors has been observed in the One-phase ON stepping excitation method, with the lowest power requisite as compared with the other stepping excitation methods. But, at higher speeds, it demonstrates less stability. In the two-phase ON stepping excitation method, the power requirements are higher, but the torque developed is better because of the reversal of the input polarity of the phases to perform a new step. The One-two-phase ON stepping excitation method has the highest torque and stability at high speeds, in addition to the highest resolution.

Conclusions

The PLC LOGO 8! can control a group of stepper motors in any order desired for each motor. The desired sequences involve direction, angular displacement, and angular velocity. An industrial motor driver system based on a stepper motor and the PLC LOGO 8! type can be used for robot arms. The motion control algorithm of multiple stepper motors was effectively implemented in this study. Three factors of each of the employed multiple stepper motors were controlled. These factors are: (1) rotational direction was altered by altering the sequence of pulses given to the stepper motor coils. (2) The angular displacements were regulated by controlling the number of direct I/p electrical pulses to the stepper motor coils. (3) Speed: The angular speed is determined by the period of the control signal. If these motors were utilized in robot arms, these settings could be simply modified to implement any desired function. Furthermore, a single PLC may operate many motors by adding and programming more I/P and o/P modules. In future work, PLC type Siemens S7-1200 can be used instead of the LOGO! 8 PLC as it has many advanced features useful for close-loop systems and for expanding the system by increasing the number of motors on the robot arm. Also, a CNC machine drive-based PLC can be designed and implemented in future work.

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