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Didactic prototype of a robotic manufacturing cell to program welding trajectories in a frame

Prototipo didáctico de una celda de manufactura robotizada para programar trayectorias de soldadura en un chasis

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Abstract

This project shows the integration of a didactic prototype of a robotic manufacturing cell for the programming of welding trajectories in a chassis. The purpose of this project is to integrate the robotic cell through the interaction of the controller of an industrial robot, a programmable logic controller (PLC) and a power transmission system for the positioning of a chassis for didactic purposes for students studying engineering in the area of Industrial Automation. To carry out the project, a scale chassis for a tractor and its support base was first manufactured, then the control of a stepper motor was carried out through a SIMATIC S7-1200 CPU 1214C PLC and a microstep driver module. The programming software COSIMIR from FESTO was also used to program the welding trajectories in a Mitsubishi RV-2AJ robot with 5 degrees of freedom that interacts with the PLC through input and output digital modules. Finally, it was possible to obtain a functional prototype of a robotic manufacturing cell that can be used for teaching robot trajectory programming and that is closely related to industrial machines.

Didatic, Integration, Prototype

Resumen

En el presente proyecto se muestra la integración de un prototipo didáctico de una celda de manufactura robotizada para la programación de trayectorias de soldadura en un chasis. El propósito de este proyecto es integrar la celda robotizada a través de la interacción del controlador de un robot industrial, un controlador lógico programable (PLC) y un sistema de transmisión de potencia para el posicionamiento de un chasis con fines didácticos para los alumnos que cursan una ingeniería en el área de Automatización Industrial. Para realizar el proyecto primeramente se fabricó un chasis a escala para un tracto camión y su base de soporte, enseguida se realizó el control de un motor a pasos a través de un PLC SIMATIC S7-1200 CPU 1214C y un módulo microstep driver. También se utilizó el software de programación COSIMIR de FESTO para programar la trayectoria de la soldadura en un robot Mitsubishi RV-2AJ de 5 grados de libertad que interactúa con el PLC a través de sus módulos de entradas y salidas digitales. Finalmente se pudo obtener un prototipo funcional de una celda de manufactura robotizada que puede utilizarse para la enseñanza de programación de trayectorias de robots y que tiene una amplia cercanía con las máquinas industriales.

Didáctico, Integración, Prototipo

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Introduction

Currently in public institutions in Mexico, it is an important challenge to achieve significant learning in students, especially those who are currently studying engineering. Specifically in the state of Guanajuato in Mexico, large car assembly plants have been installed which brings with it increasingly complex production processes, so it is necessary to have trained personnel to meet the labour demands of this industrial sector and now with the new trends of industry 4.0, will bring major technological, social, economic and educational changes.

The automotive industry is a sector that is characterised by a high demand for skilled labour, which is why recently graduated engineering students who do not have work experience in the manufacturing industry find it difficult to adapt quickly to the labour sector due to their lack of professional experience or, what is more complicated, lack of opportunities to obtain their first job.

(Márquez and Pinargote, 2022), indicate that nowadays education in general requires a change in the teaching method, where the teacher must be willing to develop certain skills outside the context of the traditional curriculum, knowing the ways to implement holistic, active and practical teaching that best suits the day to day.

Consequently, it is necessary to develop didactic prototypes that contribute to the meaningful learning of students, (Diaz, Casachagua, Ortiz, Cuellar and Raymondi, 2022) mention that these prototypes are an alternative to the lack of equipment in workshops and/or teaching-learning laboratories in educational institutions of basic and higher education.

However, in basic industrial robot programming courses, the trajectories of the robot tool are generally programmed with different coordinate systems and some geometric figures are used as trajectories: circles, triangles, squares and curved lines to simulate the robot performing a specific task.

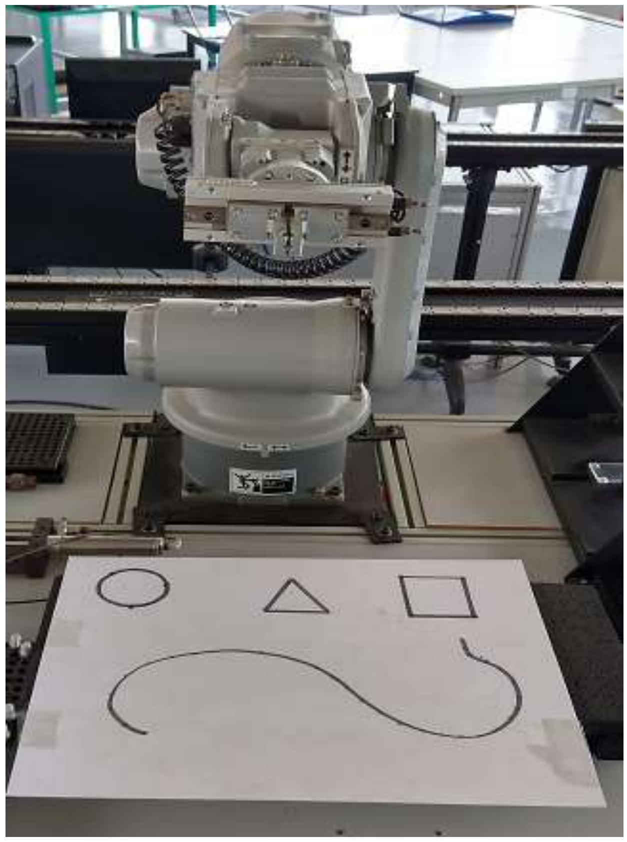

Figure 1 Trajectories of the robot with geometric figures
Own Authorship

Therefore, the students only learn to record points to generate a robot trajectory with geometric figures, but they do not understand the relationship that exists in an industrial process such as applying paint, welding or for making an assembly, so the programming logic is lost when faced with a real problem.

Problem statement

Based on the educational programs of the Automotive Engineering careers of the Polytechnic University of Guanajuato, it is proposed that several graduates will be working in the area of manufacturing processes and automation. With the development of this robotic cell, students from the Automotive Engineering areas will acquire skills for programming the trajectories of a robot in the welding process and will also understand the interaction between a PLC and the input and output modules of the controller of an industrial robot in a manufacturing cell. This will help graduates to adapt quickly to the demands of the labour sector based on Industry 4.0 in the future.

Cell integration

The robotic cell consists of a Mitsubishi RV-2AJ 5-degree-of-freedom robot with a 2 kg payload capacity, a SIMATIC S7-1200 CPU 1214C DC/DC/DC PLC, a power transmission system, a 1.8° stepper motor per step, a 9-42 VDC microstep driver module, a chassis for a scale built tract truck with its support, the COSIMIR programming software from FESTO for programming the robot trajectories and the TIA PORTAL V13 programming software for programming the PLC. Its principle of operation is based on a robotic cell controlled through a PLC and an industrial robot that has the ability to program the welding process trajectories on a chassis and through a power transmission system, the chassis is positioned as required by the process. In the following sections, the methodology followed for the realisation of the project is presented.

Design and manufacture of the chassis

Firstly, the model of a chassis for a tractor truck with its powertrain system was chosen; then the 3D modelling of each of the parts was started in SolidWorks 2019 software. Once we had the 3D model, we proceeded to manufacture the chassis components using a CNC machining centre and a 3D printer, which was used to manufacture some of the differential components.

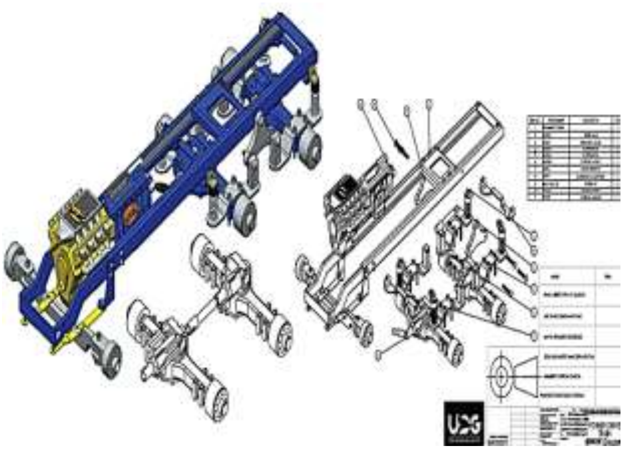

Figure 2 Virtual prototype of the chassis
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Once the chassis parts were fabricated, the final assembly was carried out. A frame was also required to act as a means of support for the chassis and the power transmission system.

Figure 3 Physical prototype of the chassis
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Power transmission system

The power transmission system consists of the stepper motor, a coupling, a speed reducer with a 20:1 ratio, a synchronous belt drive that helps to ensure synchrony between the stepper motor and the chassis, as well as preventing slippage between the belt and the pulleys. This system is used to rotate the chassis to the desired position so that the robot then follows the trajectories programmed in the welding application.

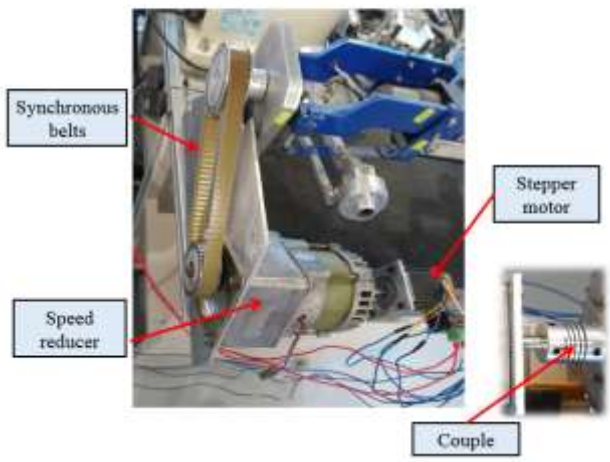

Figure 4 Power transmission system
Own Authorship

Stepper motor control with the PLC

A stepper motor with two 3A windings and a positioning accuracy of 1.8° per step was used to position the chassis. The stepper motor was controlled by a SIMATIC S7-1200 CPU 1214C DC/DC/DC PLC, a microstep driver module DC: 9-42 VDC, a 24 VDC 4A voltage supply, a pushbutton panel and the programming software TIA PORTAL V13. To start with the motor control, first the PLC characteristics were registered in the TIA PORTAL V13 program, then the hardware was programmed to activate the PTO/PWM fast pulse generator with PTO pulse A and B direction options.

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The PTO pulse A pulse is used to send pulses to the motor and the PTO output B direction is used to change the motor rotation.

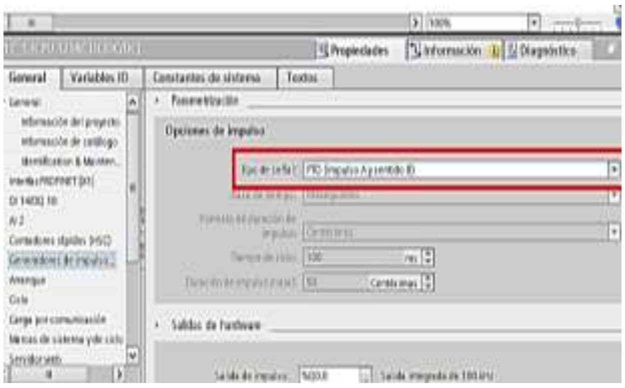

Figure 5 Activation of the PTO/PWM fast pulse generator
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As a next step, a positioning technology object was used within the PLC programming. In this technological object, a wizard is used to indicate the operating parameters of the stepper motor, such as: units, the type of control with PTO type pulse output, the number of pulses per revolution, the configuration of the limit switches and the configuration of the motor dynamics.

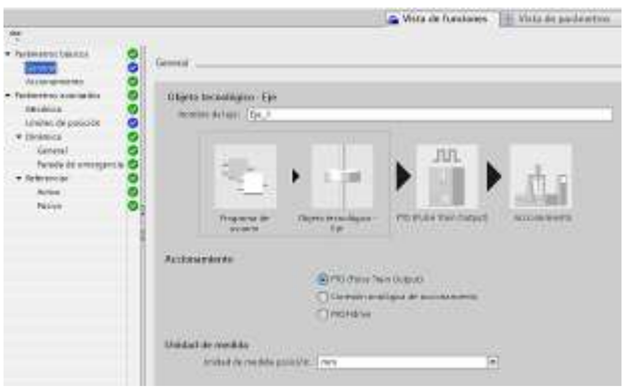

Figure 6 Stepper motor activation parameters
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Finally, to finish with the programming for the stepper motor control, an OB1 organisation block was used within the PLC project tree. This control was carried out in contact diagram (KOP) using the motion control programming tools. As a first stage of this project, two digital inputs were used to receive the chassis position signal via two inductive sensors, and two digital outputs were used to send signals to the robot to indicate the start of the trajectory programmed in the robot controller.

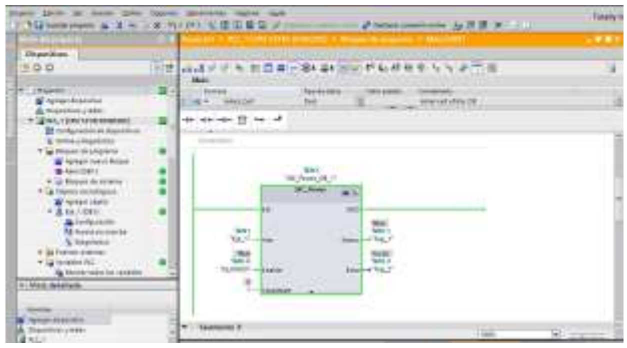

Figure 7 Stepper motor programming
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Stepper motor power stage with the Microstep Driver

As mentioned above, the motor used has two coils with an accuracy of 1.8° per step, so it requires 200 pulses to make a full 360° turn. To calculate the step angle, the following expression is used.

$$Angle\ of\ passage = \frac{360°}{(TH)\ x\ (FH)} \qquad (1)$$

Where:
TH = Number of rotor teeth
FH = Number of phases

Therefore, the stepper motor used has a 50-tooth rotor and a 4-phase stator resulting in 1.8° for each pulse sent to the controller. To make the physical connections to the motor and Microstep Driver controller, it was first necessary to identify the control and power signals in the controller, as well as the number of motor steps per revolution. In this case, if 200 pulses are required for each revolution of the motor shaft, the controller switches were positioned based on the number of pulses required in the motor.

Figure 8 Programming of the Microstep Driver for stepper motor
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To connect the power stage, the A+ A- B+ B- coils of the motor were connected to the power inputs of the Microstep controller. These connections were made as shown in the figure below.

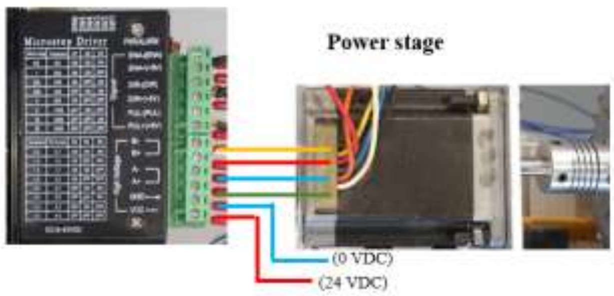

Figure 9 Stepper motor power stage
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Stepper Motor Control Stage with Microstep Driver and PLC

This stage requires connecting the pulse control outputs of the PLC to the control inputs of the Microstep Driver.

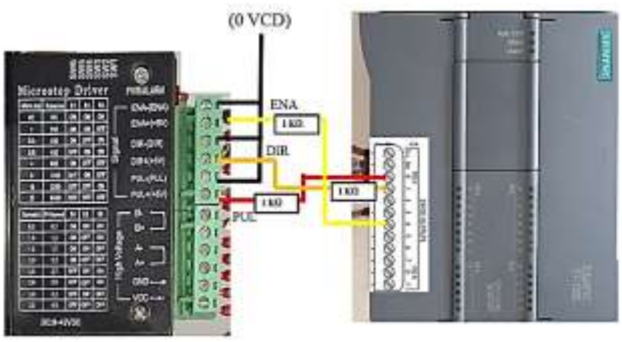

Figure 10 Stepper motor control stage
Own authorship.

To control the motor through the PLC, 4 outputs were used. Output Q0.0 (PUL) was used to send the pulses, output Q01 (DIR) to make the motor rotation change, output Q0.3 (ENA) to disable the motor when the control signal is not being sent, and output Q0.4 was used to send the cycle start signal to the robot.

In addition to the PLC outputs, 5 digital inputs were used. Input I0.0 was used to start the work cycle (STAR), input I0.1 was used to stop the work cycle (STOP), inputs I0.2 and I0.3 were used to connect the sensors that detect the position of the chassis and finally input I0.4 was used to receive the end of cycle signals from the robot.

Programming of the Mitsubishi RV-2AJ Robot with the COSIMIR platform of FESTO

The robot used in the project is an articulated robot Mitsubishi RV-2AJ of 5 degrees of freedom with a capacity to load 2 kg and a maximum radial reach of 460 mm, has a 64-bit CPU controller that allows parallel execution of up to 32 programs in multitasking mode, plus an interface module with 16 digital inputs and 16 digital outputs.

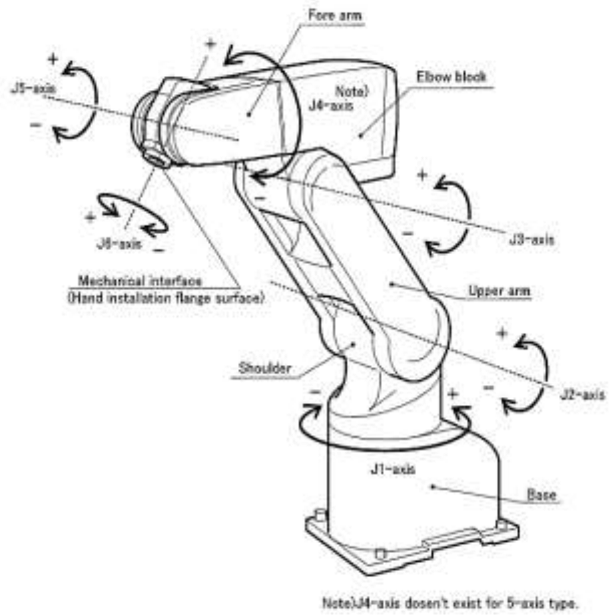

Figure 11 5-degree-of-freedom robot joints. Taken from Mitsubishi Industrial Robot RV-1A/RV-2AJ Series, Standard Specifications Manual (CR1-571 Controller (p. 2-10), Mitsubishi Electric Europe B.V. Germany, (2009).

The robot can be programmed through its teach pendant control panel or also with the COSIMIR programming software from FESTO, which is a graphic software based on the MELFA-BASIC-IV programming language that helps to easily program the trajectories to be carried out with the robot.

The communication interface between the robot controller and the computer is via an RS232 port, as well as a module with 16 digital inputs and outputs that help to communicate the robot with the outside world.

When creating a new project, 5 windows are opened.

1. Robot Observation window is used to observe the movements performed by the robot.

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2. Programming window: in this window, the program codes are displayed.

3. Error Report Window: this window is used to check that there are no errors in the programming.

4. Model Scan Window: used to observe the programs loaded inside the Robot if the connection between the CP and the Robot has been established.

5. Positions window: this window is used to save the robot's Positions for later use in the programming window.

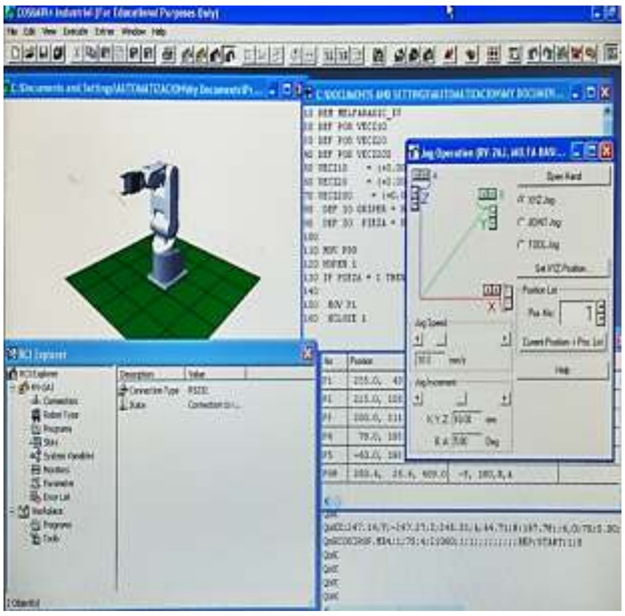

Figure 12 Programming of the robot trajectories
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To generate the programming of the robot trajectories, the Joint coordinates, Cartesian coordinates or tool coordinates of the robot are used to position the tool tip in the areas where the welding is to be applied. Then the points where welding is required are saved until a work cycle is generated. Finally, the robot input that receives the PLC signal to indicate the start of a work cycle once the power transmission system has positioned the chassis, and a digital output in the robot output module to send the signal that the work cycle has been completed, are registered.

Results

Based on the stages and the integration of the systems in the development of this project, such as the design and manufacture of the chassis, the stepper motor control system through the SIMATIC S7 1200 PLC and the Microstep Driver controller, the Mitsubishi RV-2AJ articulated robot with 5 degrees of freedom and the COSIMIR programming software from FESTO to programme the robot trajectories, it was possible to develop a functional prototype of the robot; a functional training prototype was developed for engineering students in the area of industrial automation, which has the capacity to simulate the trajectories of the welding process in a robotised cell where the student recognises the interaction for programming a PLC and the controller of an industrial robot as part of a hierarchy of the pyramid of industrial networks that are part of Industry 4. 0.

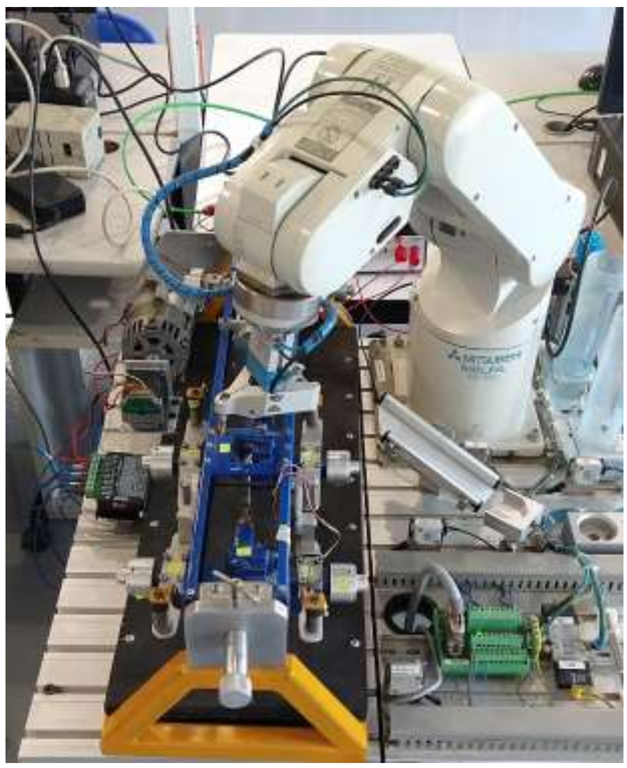

Figure 13 Final prototype of the robotic cell
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Conclusions

With the completion of this project, the initial objectives set at the beginning of the project were met, as a functional didactic prototype was integrated, which has some advantages compared to traditional ways of teaching robot trajectory programming, to mention a few:

- Programming of a logical sequence of trajectories of an industrial robot for work cycles in a welding process.

- Control of a stepper motor with the PLC and Microstep Driver.

- Interaction of a PLC with the controller of the industrial robot.

Finally, this project has several areas of improvement such as: the positioning of the chassis can be achieved through a servomotor controlled with the PLC instead of a stepper motor, integrating an HMI connection interface to monitor the processes in real time, generating the connection protocol between the PLC and an industrial network.

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