Design and integration of the Control and Communication System of a conveyor belt and a robotic arm using Modbus and IoT applied to the educational industry

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***Abstract*—In today's rapidly evolving industrial landscape, hands-on experience with Industry 4.0 technologies is critical for engineering students. This paper presents the development of a Cyber-Physical System (CPS) designed to enhance practical learning by integrating a conveyor belt, a 6-degree-of-freedom robotic arm, and IoT-enabled control within an educational framework. The system connects an unused conveyor module with a newly acquired robotic arm through Modbus TCP/IP communication, with a Schneider M221 PLC acting as the main controller. A Raspberry Pi serves as the IoT hub, allowing for remote data monitoring and control via Node-RED.**

The training module includes a complete setup of industrial components—contactors, thermal relays, an HMI, push buttons, indicator lights, and a frequency drive—providing a realistic simulation of automated systems. Initial tests have successfully demonstrated Modbus TCP connectivity between the Raspberry Pi and the PLC, as well as the direct kinematics for the robotic arm.

Expected results include the synchronized operation of the conveyor and robotic arm, remote IoT monitoring, and a scalable platform for future expansions. This CPS aims to serve as an accessible, cost-effective educational tool that aligns with modern industrial demands, bridging the gap between theoretical knowledge and practical, hands-on learning.

***Index Terms*—Cyber-Physical System (CPS), Industry 4.0, Educational Automation, Modbus TCP/IP, IoT, PLC, Node-RED, Robotic Arm Integration, Direct Kinematics.**

I. INTRODUCTION

Various training systems have been developed for learning automation with the aim of providing solutions to everyday problems in industrial plants, such as automating processes with conveyor belts, filling liquid tanks, heating ovens, etc.

The contributions and what was identified as missing in said works are detailed below:

- **Development and Validation of a Less Expensive and Portable PLC Module for Students Training in Industrial Automation.** A PLC is designed completely from scratch, so that it is portable, with specific characteristics defined by the developer and using electronic design criteria according to established IPC standards. However, it does not incorporate an additional part such as an HMI screen, wired logic, any particular plant or process, nor does it provide the reliability in semi-industrial environments as well-known commercial brand PLCs do. [2]
- **Analysis and Interface Design for Arduino based PLC connection with Allen Bradley PLC via Ethernet.** A communication code was developed for the PLC and the microcontroller using a Flask framework that allows creating an HTTP server in addition to an IOT interface with high software features. However, the analysis of said communication is missing in application to an industrial plant, such as a conveyor belt and a robotic arm. [4]
- **Building a Training Module for Modern Control** A transparent system is designed and built for the user where all the practices focused on process control, tuning and understanding the operation of the control can be deployed from the HMI implemented in a touch panel for the control of two independent processes that allow the development of different laboratory practices giving students the necessary tools for their development in the professional area. However, a part of a clearly wired logic is not implemented, nor an area to incorporate a microcontroller to work some type of industrial communication between two different central processing units. [3]
- **Design of pick and place arm for conveyor belt using PLC.** This project aims to develop an autonomous system capable of transferring elements or materials from one place to another efficiently using servomotors, hydraulic and pneumatic systems. However, the project does not incorporate industry 4.0 or IIoT technologies in plant automation that allow the recording of the production process for the subsequent study of the plant's efficiency. *Babu Shridhar Kambli, Atmaram Avinash Shetkar, 2024.*

Considering the findings and gaps in these studies, this article proposes the design of a mechatronic system for educational purposes that integrates a conveyor belt and robotic arm with IoT connectivity via Modbus TCP/IP. The system aims to enhance students' practical training by simulating real industrial processes in a semi-industrial environment, leveraging components like a PLC, HMI, contactors, thermal relays, and frequency drives to achieve a cost-effective and accessible training solution.

II. METHODOLOGY

Based on the project proposal, the development process has been divided into the following key stages:

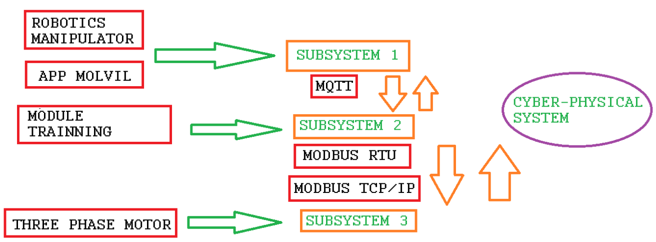

Fig. 1. Subsystems that make up the cyber-physical system

A) ROBOTICS MANIPULATOR The robotic manipulator in this project is a 6-degree-of-freedom (6DOF) arm designed to perform precise positioning tasks in coordination with the conveyor system. A direct kinematics model was implemented to calculate the end-effector's position based on the joint angles provided. This kinematic model allows for the real-time calculation of the manipulator's Cartesian coordinates, ensuring that the arm reaches specified points within its workspace accurately.

Fig. 2. HiWonder 6 DOF Robot

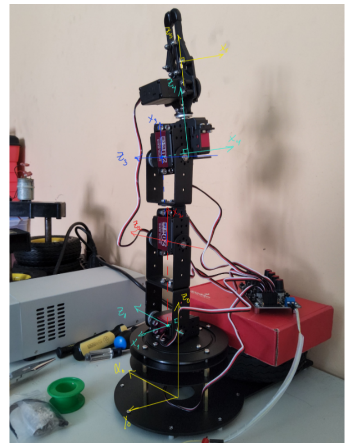

Fig. 3. direct kinematics

This direct kinematics implementation provides a foundation for future integration with inverse kinematics, supporting more complex tasks and expanding the range of applications for this educational robotic system.
To facilitate user interaction, a control code was developed using the Thonny IDE. This code allows operators to input specific angles for each of the manipulator's six joints, which are then processed to determine the precise position of the end effector. The program calculates and displays the x, y, and z coordinates, enabling accurate control and verification of the manipulator's movements.

B) APP MOVIL

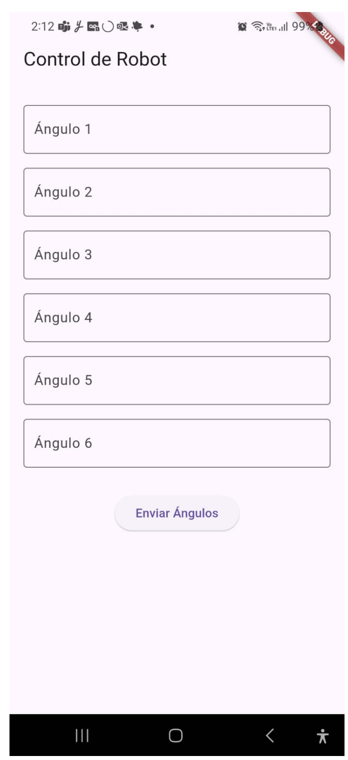

Fig. 4. App movil delevlopment on Flutter

C) TRAINING MODULE

The training module was developed using a pre-existing stand available in the laboratory, which served as the foundation for the physical setup. To complete the module, additional components were acquired, including a Schneider M221 PLC, electromagnetic contactors, relays, a thermal relay, push buttons, pilot lights, a selector switch, a Human-Machine Interface (HMI), and a frequency drive. These components enable the creation of an educational system designed to simulate real-world industrial automation processes.

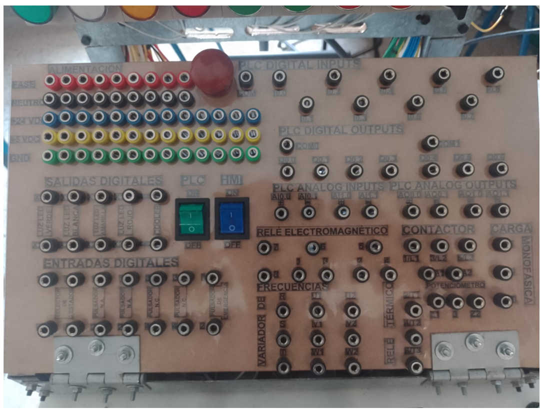

Fig. 5. Training module management panel with their respective labels

This module aims to provide students with practical experience in industrial automation, focusing on the control and operation of a conveyor belt integrated with a robotic arm. The Schneider M221 PLC acts as the primary controller, facilitating communication between the conveyor system and the robotic arm. Together with the HMI, the PLC provides a user-friendly interface through which users can monitor and control key system parameters—such as conveyor speed and robotic positioning—in real time.

Fig. 6. Wired automation and logic equipment mounted to the training module

A dedicated control panel was designed to organize these elements for accessibility and maintenance. This panel includes various controls, such as push buttons and selector switches, while indicator lights and the HMI display offer immediate feedback on system status and operations. The integration of the thermal relay and contactors ensures system safety, protecting against overloads and supporting stable, reliable performance.

Fig. 7. Front view

Overall, this training module replicates industrial setups while supporting IoT-based remote monitoring and data tracking. By incorporating these capabilities, the module aligns with Industry 4.0 standards, offering a robust platform for students to acquire skills in modern automation and IoT-integrated systems.

D) IoT DESIGN: MQTT

The IoT component of this project focuses on developing a system that integrates a robotic arm and a conveyor belt, enabling remote control and real-time monitoring. Using Modbus communication, the system allows for the transmission of control commands and data between devices. A mobile application is designed to interact with the system, allowing users to input desired kinematic angles for the robotic arm, move the robot, and monitor its end-effector position. The app also serves as a dashboard for controlling the conveyor belt and provides real-time monitoring of key data, offering an intuitive interface for educational purposes in the field of mechatronics.

- IIoT communication system design
  MQTT is an OASIS standard messaging protocol for the Internet of Things (IoT). It is designed as an extremely lightweight publish/subscribe messaging transport that is ideal for connecting remote devices with a small code footprint and minimal network bandwidth. MQTT today is used in a wide variety of industries, such as automotive, manufacturing, telecommunications, oil and gas, etc.

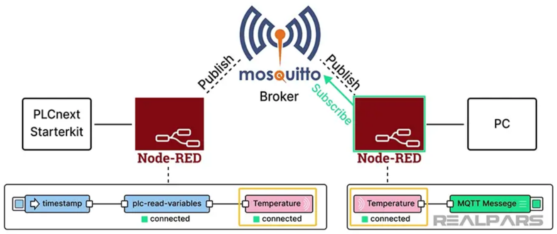

Fig. 8. MQTT communication architecture

E) Modbus protocol
Modbus is a communication protocol commonly used in industrial automation systems. It was developed in the late 1970s by Modicon (now Schneider Electric) and has since become a widely adopted standard in the industry. Modbus facilitates communication between devices connected on a serial bus or Ethernet network, allowing them to exchange data and control signals.

Fig. 9. Connection in physical layer through Modbus RTU

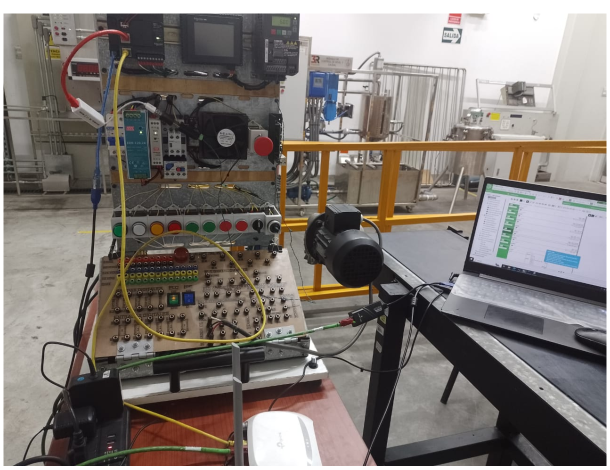

Fig. 10. Connection in physical layer through Modbus TCP/IP

F) Three Phase Motor

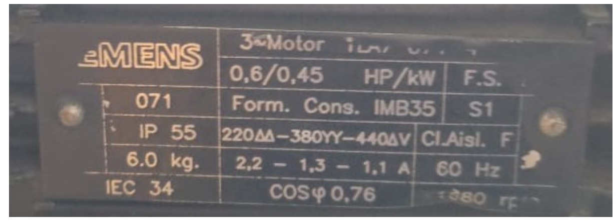

Fig. 11. Motor plate

By perfectly controlling the acceleration and deceleration of long conveyor belts, mechanical stress on all drive system components and the conveyor belt itself is reduced. This extends the life of the belt and other components, increasing resource availability and reducing operating and maintenance costs. Having the flexibility to control the speed of long conveyor belts can help optimize the entire system by reducing bottlenecks and maximizing the efficiency of material flow processes, which in turn leads to savings in operating costs.

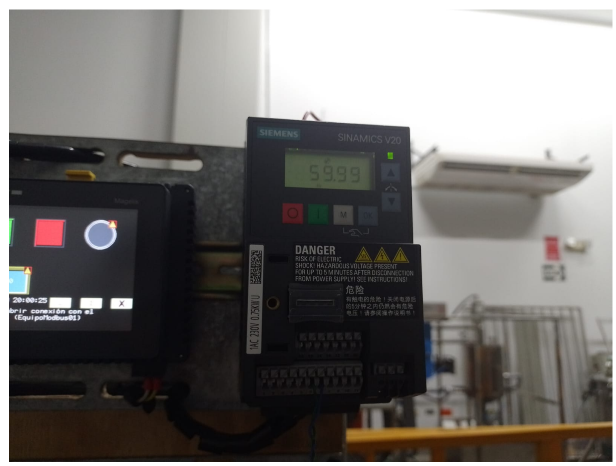

Fig. 12. SINAMICS V20

G) User interface development
The evolution of IIoT user interfaces reflects a continuous effort to address the unique challenges posed by industrial environments. As technology advances, incorporating innovations such as context-aware design, AI, and responsive interfaces becomes pivotal. Striking a balance between complexity and intuitiveness, IIoT UIs are poised to play a central role in enhancing the efficiency and usability of industrial processes in the ongoing Industry 4.0 journey.

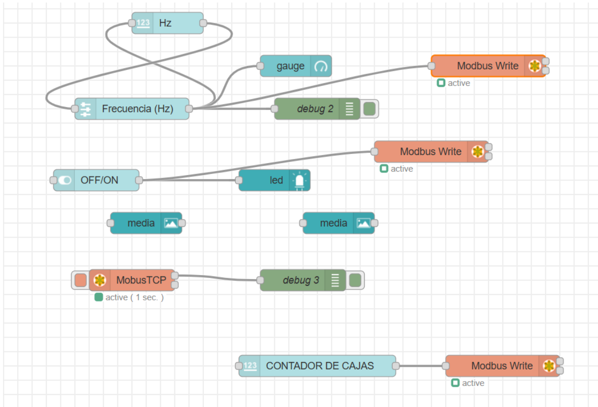

Fig. 13. Modern graphical interface

Fig. 14. Modern graphical interface

III. RESULTS

Significant progress has been made in the development and integration of the IoT system for the robotic arm and conveyor belt. The direct kinematics model for the robotic arm has been successfully implemented, enabling precise control over the arm's position based on the input joint angles. Additionally, the connection of the training module has been completed, facilitating the integration of the robotic arm and conveyor belt within the educational framework.

A key advancement in the project is the establishment of communication between the Raspberry Pi and the PLC via the Modbus TCP protocol. Initial tests are currently being conducted to ensure stable and efficient data transmission between the devices. Moreover, early-stage trials with Node-RED have been carried out, providing a user-friendly interface for controlling and monitoring the system components in real-time. This platform enables seamless interaction with both the robotic arm and the conveyor belt, enhancing the overall functionality of the system.

These developments represent a significant step towards the successful implementation of an IoT-based control and monitoring system, offering practical applications for educational purposes in mechatronics and automation.

IV. CONCLUSIONS

This work demonstrates the successful integration of IoT technologies into the control and monitoring system of a robotic arm and conveyor belt, aimed at enhancing educational experiences in mechatronics. The implementation of direct kinematics for the robotic arm, along with the completion of the training module connection, provides a solid foundation for future development.

The establishment of communication between the Raspberry Pi and the PLC via Modbus TCP marks a significant milestone in ensuring seamless interaction between hardware components. Initial testing with Node-RED further contributes to the system's functionality, offering a user-friendly interface for real-time monitoring and control.

While the system is fully operational for the current phase of the project, further work is needed to refine the communication protocol and optimize the user interface for practical use. Future developments will focus on expanding the system's capabilities, improving performance, and conducting extensive real-world testing in educational environments.

Overall, this project showcases the potential of IoT systems in industrial and educational applications, offering a flexible and interactive platform for students to learn about automation, robotics, and mechatronics.

The proposed solution seeks to improve the solutions provided in the field of automation by students about to graduate and enter the workforce, however, it should be noted that if this solution is to be brought to the labor field, some modifications must be made to the proposed architecture, such as, for example, changing the Rasberry Pi 4 for IoT gateways, and if the use of node-red is also required, a database must be placed between the gateway and an instance launched, for example, in AWS, so that the IIoT solution in the field of automation is efficient.

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