DOI:10.5937/IIZS26154R

DEVELOPMENT OF DIDACTIC PLC SIMULATOR AND ITS INTEGRATION WITH A VIRTUAL 3D ENVIRONMENT

Research paper

Aleksandar Reljić[1*], Saša Prodanović[2]
[1,2]University in East Sarajevo, Faculty of Mechanical Engineering, East Sarajevo, Republic of Srpska, Bosnia and Herzegovina

Abstract: The paper represents the development of a didactic PLC simulator and its connection with a virtual 3D environment for educational purposes in the field of PLC programming within industrial automation and mechatronics. The developed software enables the creation, execution, and visualization of control programs in real-time based on the Ladder Diagram programming language. Bidirectional communication between the PLC simulator and the virtual 3D model was achieved, enabling continuous exchange of input and output signals, as well as synchronization of the logical control algorithm with the visual representation of the process.
Key words: PLC simulator, ladder diagram, digital twin, virtual 3D environment, industrial automation, virtual commissioning, didactic model

INTRODUCTION

In current research, significant attention has been paid to the development of Digital Twin systems in industrial automation, focusing on the possibilities of real-time synchronization between physical and virtual systems (Hrbček et al., 2026; Schamp et al., 2019). Particular emphasis has been placed on the development of architectures that enable data exchange between PLC control systems and their digital representations, utilizing standards such as IEC 61131-3 and OPC UA (Hrbček et al., 2026; Schamp et al., 2019). The field of Virtual Commissioning has also been intensively researched in recent years. Solutions have been presented that allow for the testing of PLC programs before the actual system is put into operation, thereby reducing development time, the number of errors, and implementation costs (Striffler & Voigt, 2023; Ortiz et al., 2026). Special attention has been devoted to the development of simulation models and their connection to industrial PLC devices, where the work of (Zhang, 2024) stands out. In that research, an educational PLC simulator was developed for learning programming, simulating the operation of automated systems, and performing laboratory exercises in a virtual environment without the need for expensive industrial equipment. Research has shown that Digital Twin and Virtual Commissioning represent an important direction in the development of modern industrial automation.
Starting from the actual needs in the field of student education and the idea of creating a software-based educational model, this paper represents the development of a didactic PLC simulator and its integration with a virtual 3D environment.
The objective of this work is the development of a PLC simulator with support for Ladder logic programming language and its connection to a 3D environment for visual simulation of automatic control system operations. The developed solution enables a bidirectional exchange of input-output signals between the PLC simulator and the virtual 3D model, functionally establishing a Digital Twin environment suitable for demonstrating PLC program operation and conducting laboratory exercises in the educational process.
The paper is organized into four sections. The introductory part provides a brief overview of current research in the fields of Digital Twin systems, Virtual Commissioning, and PLC simulators, as well as the objective of the work. The second chapter describes the development of the didactic PLC simulator and its connection to the virtual 3D environment. The third chapter presents an example of implementing a sorting task for objects of different lengths, an explanation of the program networks, and visualization of the operation in the 3D environment. At the end of the paper, conclusions are given regarding the achieved results and the possibilities for applying the developed system in the education process.

[1]Corresponding author, reljic94@gmail.com, ORCID: 0009-0002-3280-3724
[2]sasa.prodanovic@ues.rs.ba, ORCID: 0000-0003-2682-6022

DEVELOPMENT OF THE PLC SIMULATOR AND ITS CONNECTING WITH 3D ENVIRONMENT

With the goal of developing a didactic system for PLC control simulation, a PLC simulator was developed that allows for the creation, editing, and execution of programs in the Ladder programming language. The primary objective during the design of the simulator was to develop a modern teaching tool that would allow users to perform laboratory exercises and verify PLC logic without the need for real industrial equipment or the acquisition of software solutions that involve a significant expenditure for the user. Special attention was paid to a simple user interface, logic execution visibility, and the ability to connect to a virtual 3D model. The simulator was developed in the Python programming language, which was chosen due to the ease of creating a graphical user interface, the large number of available libraries, and good support for developing applications that require data processing and communication between different software systems. This approach enabled the development of a flexible software solution suitable for further development and adaptation to various educational tasks. The developed PLC simulator consists of several functional units. The central part of the system is the Ladder editor, which allows for the creation and modification of program networks using basic elements of PLC programming, such as normally open and normally closed contacts, output coils, memory bits, timers, counters, frequency pulse bits, and other logical functions. In addition to program creation, the simulator enables the saving and loading of projects, viewing the status of all input, output, and internal variables, contains a pre-loaded library with established basic tasks in the field of PLC programming, and the definition of tasks intended for laboratory exercises. The appearance of the PLC simulator is shown in Figure 1.

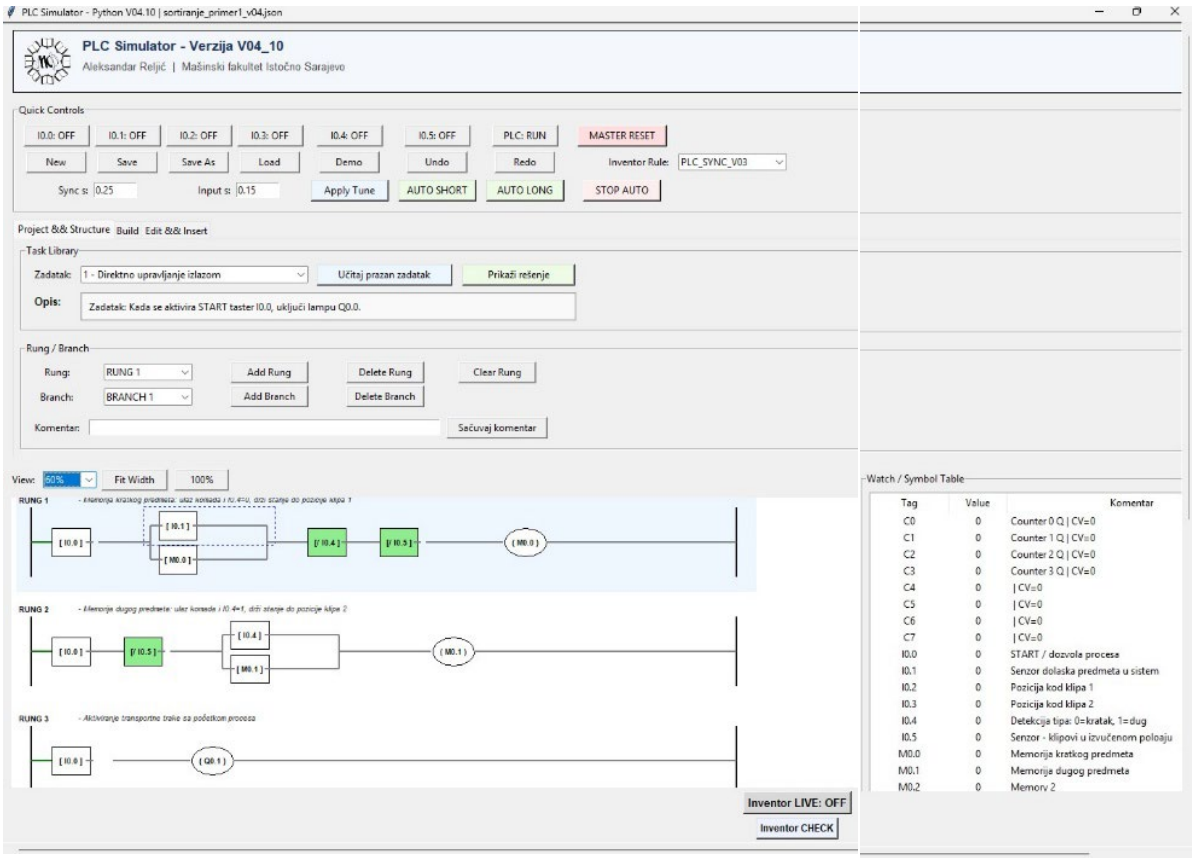


Fig. 1. *Didactic PLC simulator software*

The simulator supports two basic operating modes. In edit mode, the user creates or changes the Ladder program, adds new networks, edits comments, defines the necessary logic elements, tests the program, and so on. After finishing the program creation, code execution

mode can be accessed, where input information is activated by user clicks on corresponding buttons at the top of the window. During the execution of the logic task, active contacts, branches, and instructions are visually marked in green, allowing the user to easily follow the logic execution flow in real-time. By moving the vertical bar downwards, Global Outputs signals are accessed, where the status table for outputs, timers, counters, memory bits, and similar elements can be observed. In addition to these operating modes, the simulator has the ability to stop program operation (PLC STOP), after which the user can return to editing the logic or restarting the simulation.

In addition to the basic operating modes, the simulator includes the Inventor CHECK and Inventor LIVE functions, which enable connection to a virtual 3D environment. The Inventor CHECK function serves to verify the availability and correctness of communication between the PLC simulator and the virtual model, sending notifications in the form of messages if communication conditions are not met. The Inventor LIVE function activates bidirectional data exchange in real-time. Once communication is established, changes in the output signals of the PLC simulator are transmitted to the virtual model, while the status of the virtual sensors is automatically returned as input signals to the PLC program.

To demonstrate the operation of the PLC program, a virtual model of a didactic station with fixed mapped inputs and outputs was developed, as well as a mini-workstation for sorting objects of different lengths. The model includes a conveyor belt, input and output signals (switches/buttons and lights), and pneumatic pistons for sorting (controlled by linear actuator movement). The virtual model was developed in the Autodesk Inventor software package and serves as a digital replica of the process executed in the PLC simulator. The appearance of the virtual didactic station is shown in Figure 2.

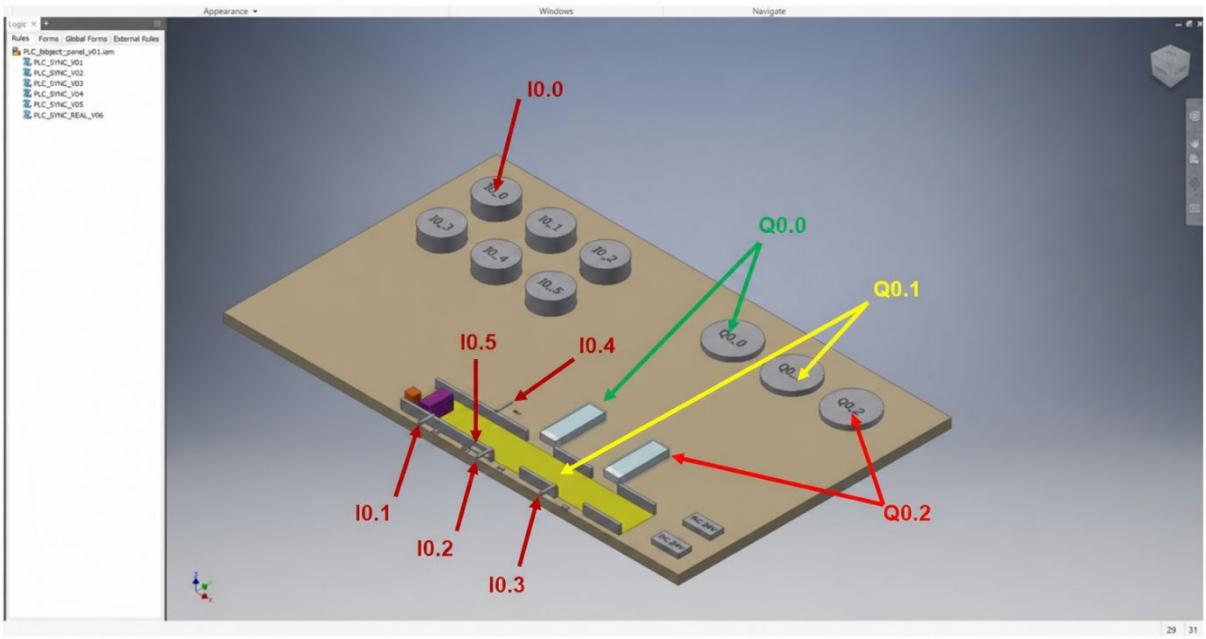


Fig. 2. *Didactic station modeled in a 3D environment*

The primary contribution of this work is the establishment of bidirectional communication between the PLC simulator and the virtual 3D environment, thereby realizing a functional Digital Twin of the system. Synchronization is achieved through a real-time data exchange mechanism using Python tools, where both software systems use a common set of input and output signals defined through user parameters.

When a user initiates the execution of a Ladder program, the PLC simulator reads the state of the input signals in each execution cycle and determines the values of the output signals based on the defined logic. The resulting values are transferred to the virtual model, where they trigger corresponding output functions, such as moving pneumatic pistons, activating lights,

and so on. Simultaneously, the virtual model continuously monitors sensor states and updates the values of the input signals. Every change of input signals in virtual model is returned to the PLC simulator. In this way, the simulator has new information about the process state in the next execution cycle, achieving continuous bidirectional data exchange between the logical and visual parts of the system.
To achieve this communication, a set of shared user parameters was defined, representing the link between the PLC simulator and the virtual model. The parameters include input and output PLC signals, as well as auxiliary parameters for controlling pneumatic pistons and other process elements. Their representation is given in Figure 3.

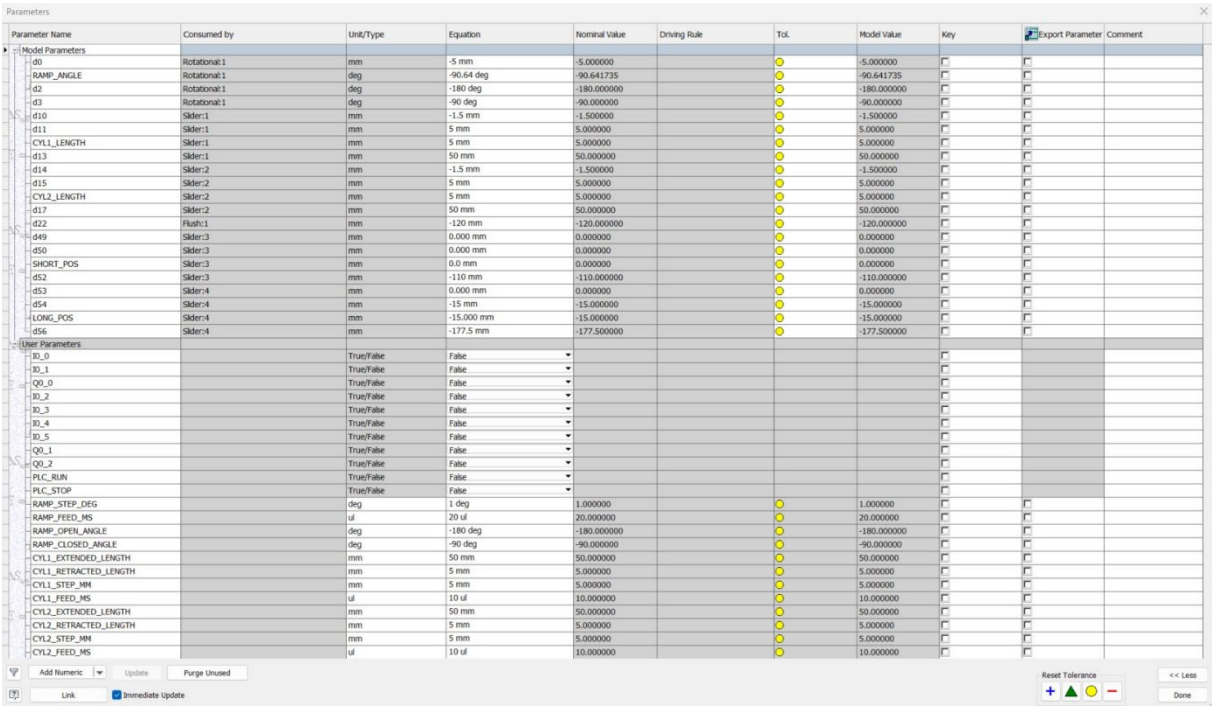


Fig. 3. *Control parameters for the synchronization process between the PLC simulator and the 3D environment*

Based on changes in the values of these parameters, corresponding iLogic procedures are executed to trigger animations, update the positions of moving elements, and change the status of virtual sensors, ensuring complete synchronization between the PLC simulator and the virtual 3D environment.
In the described manner, full synchronization between the logical and visual components of the system is achieved. Every change in the state of the PLC simulator's output signals causes a corresponding change in the 3D model. This enables real-time simulation of automated system operation, making the developed solution suitable for demonstrating PLC control principles and conducting laboratory exercises in the education system.

EXAMPLE TASK FOR SORTING OBJECTS OF DIFFERENT LENGTHS

As an example of the developed system, an automatic process for sorting objects of different lengths was implemented. The system consists of a conveyor belt, sensors for registration and determination of object length, two pistons for sorting objects, and corresponding input-output signals. After starting the process, the conveyor belt brings the object to the detection zone. Based on the signal from the sensor, it is determined whether the object is short or long, after which the PLC program activates the appropriate piston and directs the object to the designated location. Upon completion of sorting, the system returns to a state of waiting for the next object.

Input signal I0.0 represents the switch for starting the object sorting process, i.e., it represents the START switch, and its activation starts the conveyor belt that delivers items ready for sorting. Sensor I0.1 registers the presence of an object on the belt, I0.2 and I0.3 indicate object positions at piston 1 and piston 2, I0.4 serves for the detection of a longer object, while I0.5 registers the final extended position of piston 1 or piston 2. Output Q0.0 controls the extension of piston 1, Q0.1 starts the conveyor belt, and Q0.2 activates the extension of piston 2.
The process control logic was implemented using the Ladder diagram shown in Figure 4. The program is organized into multiple networks, with each network performing a specific function in the sorting process.

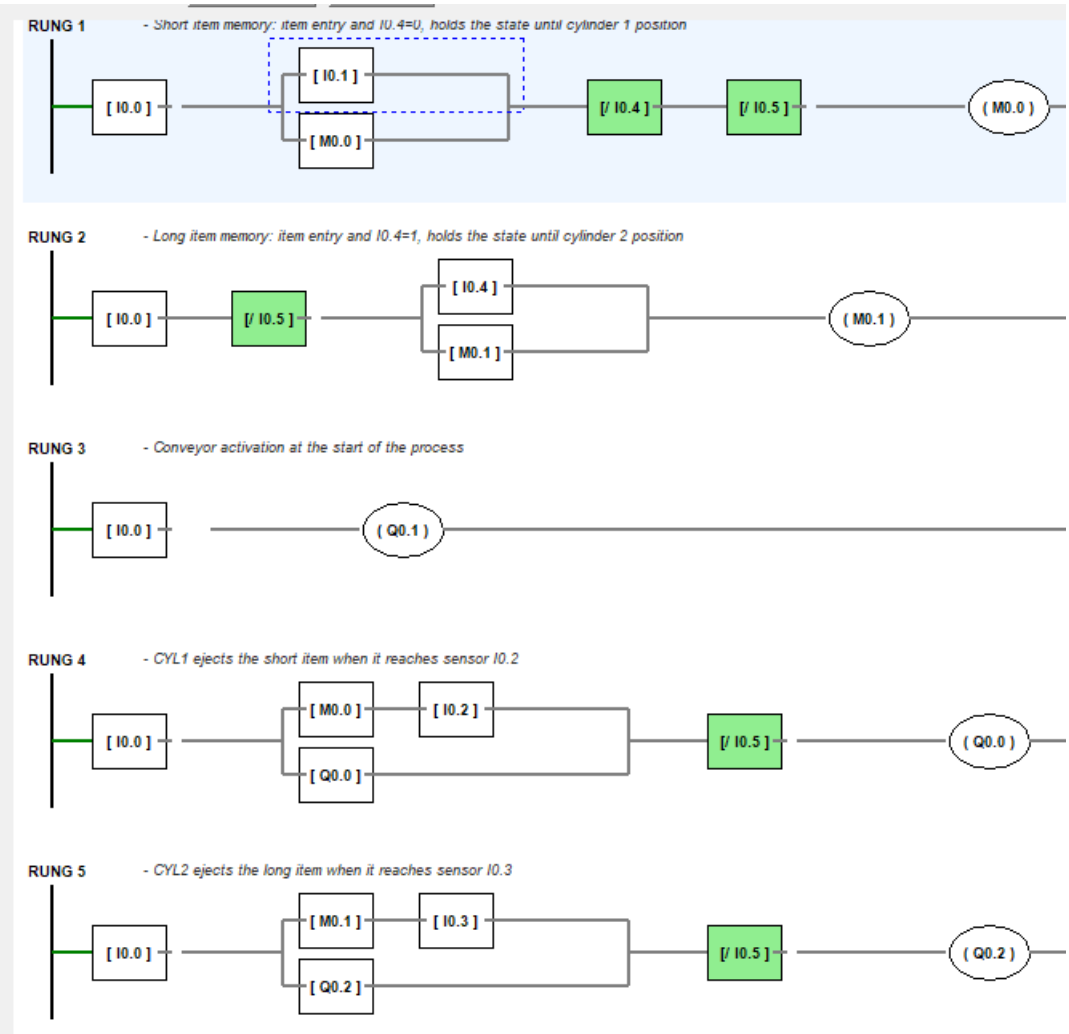


Fig. 4. *Task solution shown in the Ladder programming language*

In all networks, it is necessary for the START switch to be on for the conveyor belt to operate. Network 3 (RUNG 3) activates the conveyor belt. Network 1 registers both shorter and longer objects. Network 2 recognizes only longer objects. Network 4 defines the sorting of shorter objects with the following logic: if an object is present on the belt, if a signal for longer objects has not been registered, as soon as the object appears in front of sensor I0.2, activate output signal Q0.0 and extend piston 1, as shown in Figure 5.

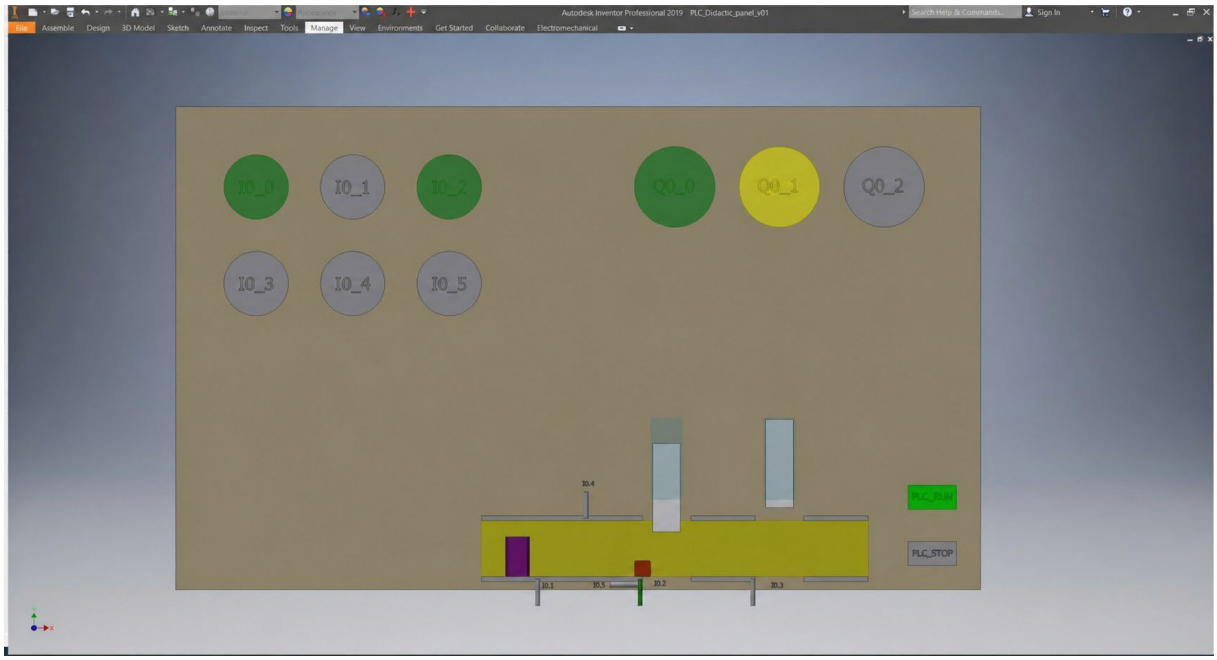


Fig. 5. *Moment of activation of piston 1 for sorting a shorter orange object*

Network 5 represents the sorting of objects of greater length. In this case, the signal from sensor I0.4 registers a longer object, and the signal from sensor I0.3 activates output signal Q0.2 and the extension of piston 2, as shown in Figure 6.

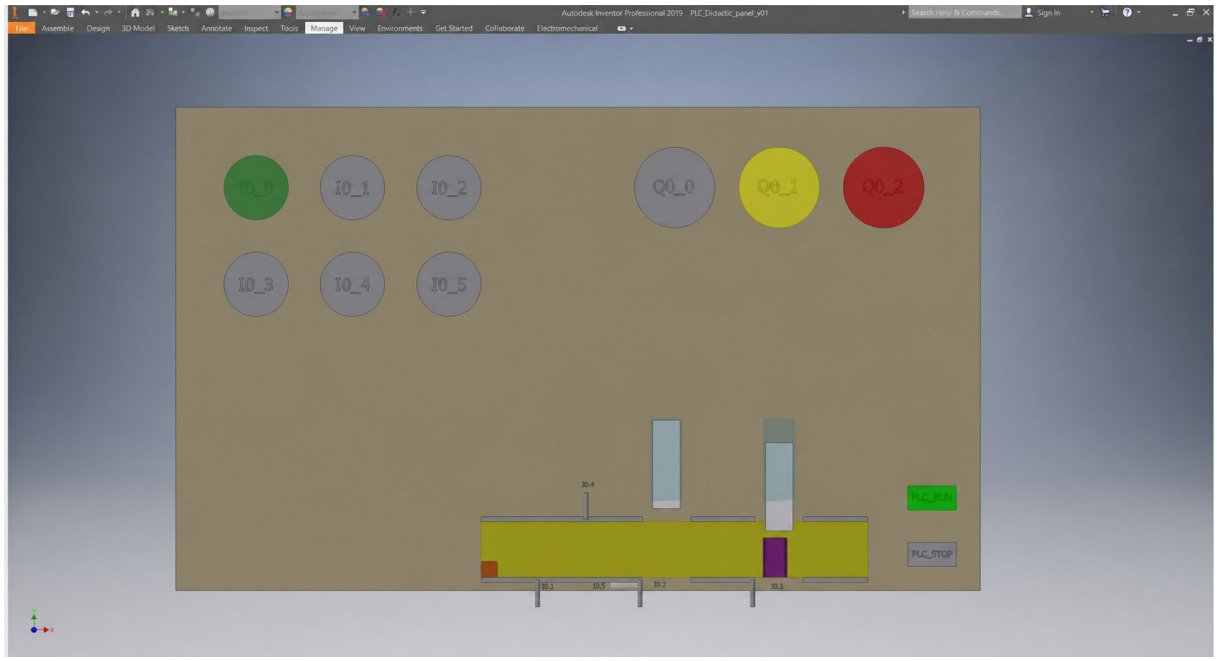


Fig. 6. *Moment of activation of piston 2 for sorting a longer purple object*

Networks 4 and 5 contain signal maintenance for the extension of the pistons due to temporary signals from sensors I0.2 and I0.3 (the object appears in front of the sensor for a short moment), as well as a normally closed contact I0.5, which serves to restart memory states and return both pistons to their initial position. The assumption is that the pneumatic pistons are single-acting and that the logistical conditions are designed so that objects on the conveyor belt arrive in an ideal arrangement.
Changes in the status of sensors I0.0, I0.1, I0.2, I0.3, I0.5 in the 3D environment are transmitted to the PLC simulator as input signals, while the output commands of the PLC

program are returned to the virtual model. This confirms the correct synchronization of the control logic and the visual model during a single object sorting cycle.

CONCLUSION

A didactic PLC simulator has been developed in this work, enabling the creation, execution, and visual monitoring of programs written in the Ladder programming language. In addition to the development of the simulator, its successful integration with a virtual 3D environment was achieved, allowing for bidirectional exchange of input-output signals between the control logic and the virtual process model. In this way, a functional system was realized that allows for simultaneous logical and visual simulation of automated process operation.
The functionality of the developed system was confirmed through the example of sorting objects of different lengths. The execution of the PLC program, the exchange of data with the virtual model, and the animation of the process occur in real-time synchronization, allowing the user to directly monitor the impact of program instructions on system behavior and more easily understand the principles of automated system operation.
A particular contribution of this work is reflected in its application in education. The developed simulator allows for the conduct of laboratory exercises without the need for real industrial equipment, providing students with the opportunity to acquire knowledge in the fields of PLC programming, automation, and mechatronics in a safe virtual environment. Simultaneously, users can monitor the execution of Ladder programs, changes in input-output signals, and the behavior of actuators in the 3D model, contributing to a better understanding of the control process. This work methodology also allows distance learning (online learning).
Beyond the costs of acquiring physical PLC devices, sensors, actuators, and didactic panels, significant financial resources are often required for the purchase of professional software tools for simulation and virtual commissioning, which are mostly licensed per user or workstation and require periodic license renewal. Furthermore, physical laboratory stations require regular maintenance, servicing and replacement of worn-out components, which further increases their cost of use. By developing a custom software solution, the possibility of performing a large number of laboratory exercises was achieved without additional license costs and without using physical equipment, resulting in significant long-term financial savings for educational institutions.
Similar advantages are cited by modern commercial systems for PLC simulation, which highlight safe testing of PLC programs, visualization of process operation, development of digital twins, support for virtual commissioning, and the conduct of laboratory exercises in a realistic virtual environment as primary benefits (MHJ Tools, n.d.).

REFERENCES

Armendia, M., Ghassempouri, M., Ozturk, E., & Peysson, F. (Eds.). (2019). Twin-Control: A Digital Twin Approach to Improve Machine Tools Lifecycle. *Springer Nature*, Cham, Switzerland.

Barale, D. (2025). Industrial Process Simulation through Digital Twin Modeling and PLC Programming. Master's thesis, *Politecnico di Torino*, Turin, Italy.

Cavalieri, S., & Scroppo, M. (2019). A CLR Virtual Machine Based Execution Framework for IEC 61131-3 Applications. *Informatica*, 43(2), 263–279.

Diekmann, M., Nitzler, J., Fischer, J., Pfisterer, H.-J., & Hartmann, D. (2026). Multi-Agent Framework Leveraging Knowledge Graphs for Virtual Commissioning Models. *arXiv preprint*, arXiv:2606.03255.

Garg, G., Kuts, V., & Anbarjafari, G. (2021). Digital Twin for FANUC Robots: Industrial Robot Programming and Simulation Using Virtual Reality. *Sustainability*, 13(18), Article 10336.

Hrbček, J., Ždánsky, J., Macko, D., & Bubeníková, E. (2026). Development of a Digital Twin Controlled by PLC in a Simulation Environment. *Transportation Research Procedia*, 93, 723–728.

Lubura, S., Mandić, Z., Prodanović, S., & Jokić, D. (2025). Procesni računari – Zbirka riješenih zadataka. *Univerzitet u Istočnom Sarajevu, Elektrotehnički fakultet Istočno Sarajevo, Akademska misao*, Beograd.

Lubura, S., & Šoja, M. (2020). Procesni računari. *Univerzitet u Istočnom Sarajevu, Elektrotehnički fakultet Istočno Sarajevo, Akademska misao*, Beograd.

Lubura, S., Šoja, M., & Ristović, M. (2013). Programabilni logički kontroleri – Zbirka riješenih zadataka. *Univerzitet u Istočnom Sarajevu, Elektrotehnički fakultet Istočno Sarajevo*.

MHJ Tools. (n.d.). PLC-Lab. Available at: *https://mhj-tools.com/products/plc-lab* (Accessed: 12 July 2026).

Ortiz, J. S., Andaluz, V. H., & Carvajal, C. P. (2026). Real-Time Digital Twin Architecture for Immersive Industrial Automation Training. *Sensors*, 26, Article 2023.

Petruzella, F. D. (2017). Programmable Logic Controllers (5th ed.). *McGraw-Hill Education*, New York, NY, USA.

Prodanović, S., & Lubura, S. (2021). Digitalno upravljanje u proizvodnji. *Univerzitet u Istočnom Sarajevu, Mašinski fakultet Istočno Sarajevo, Akademska misao*, Beograd.

Reuther, A., Plesker, C., Bassauer, D., & Schleich, B. (2026). A Digital Twin Framework for Programmable Logic Controllers in Industrial Automation Systems. *Procedia CIRP*, 139, 446–452.

Schamp, M., Van De Ginste, L., Hoedt, S., Claeys, A., Aghezzaf, E.-H., & Cottyn, J. (2019). Virtual Commissioning of Industrial Control Systems – A 3D Digital Model Approach. *Procedia Manufacturing*, 39, 66–73.

Schäfer, S., Schöttke, D., Kämpfe, T., Ralinovski, K., Tauber, B., & Lehmann, R. (2021). Design and Deployment of Digital Twins for Programmable Logic Controllers in Existing Plants. *Proceedings of the 2nd International Conference on Innovative Intelligent Industrial Production and Logistics* (*IN4PL*), 145–150.

Striffler, N., & Voigt, T. (2023). Concepts and Trends of Virtual Commissioning – A Comprehensive Review. *Journal of Manufacturing Systems*, 71, 664–680.

Zhang, W. (2024). Design of a PLC System Simulator and Application to Teaching Programmable Logic Controller Course Online. *Proceedings of the 2024 ASEE Annual Conference & Exposition*, Portland, Oregon, USA.