PLC Control of a 2-Axis Robotic Arm in a Virtual Simulation Environment

Martin Pollák(✉), Marek Kočiško, and Karol Goryl

Technical University of Košice, 1, Bayerova Street, 08001 Prešov, Slovakia
martin.pollak@tuke.sk

Abstract. The trend of automation can be observed in all areas of industrial production. Automation is an increasingly topical subject in today's continuous production process optimization era. The article aims to bring closer the field of computer-aided programming and simulation of the movement of the selected 2-axis robotic arm using PLC automation in a specific work environment. The article describes programming procedures for robotic arms used in industry, PLC automation technology programming, and simulation programs commonly used to verify the functionality of proposed robotic workplace solutions in practice. The article deals with the specific design of the PLC automatic control application in a selected Factory I/O simulation program controlling robotic arms and production equipment in a simulated workplace. The conclusion of the contribution is a reference to experimental validation of the application proposal by simulation and an assessment of its suitability for future use in practice.

Keywords: PLC Control · Virtual Simulation · Factory I/O · Robot Programming · Manufacturing Innovation

1 Introduction

An ideal modern production process only contains a human component marginally, mainly for repairs and supervision of the predominant robotic component that performs the production. Currently, primary PLC machines are responsible for controlling the robotic component, although their activity often depends on cooperation with the operator. Authors K. S. Kiangala et al. were involved in monitoring the process of filling bottles in a plant to produce beverages with an orientation to the concept of Industry 4.0. They used a Siemens S7-1200 PLC communicating via Ethernet TCP/IP with the ZENON SCADA HMI interface to monitor the process. The result of the study was the optimization of production time by reducing the number of workers' interventions in the production process [1]. The current industrial revolution aims to relieve the operator from routine and monotonous work, which production machines and robotic devices can perform through automation technology. Robot programming is the process of creating, debugging, simulating, and testing a set of instructions for the robot's control system. Authors Z. Papulova et al. contribution focused on automated production in the automotive industry. They described specific technologies associated with Industry 4.0,

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such as advanced robotics, 3D printing, the Internet of Things (IoT), and production automation. The authors analyzed the level of implementation of these technologies into other Industry 4.0 technologies. The result was findings and pointing out the need for the application of sensors, programming devices such as PLC/HMI, and industrial robots in the automation sector of production [2].

Authors CH. Brecher et al. presented the development of production with an orientation to the concept of Industry 4.0 using automation approaches and standardized automation technologies [3]. The book by K. M. Lynch et al. deals more closely with modern robotics, describing the view on mechanics, planning, and control of robots. The list of all instructions is more extensive. The programming is therefore aimed at creating the most efficient path that the robot arm and the effector have to perform at the correct timing of the individual instructions and movements and at setting the robot's interaction with the environment. The robot program is specified as commands and instructions in the robot programming language stored in its memory [4]. Another exciting book describing the use of automation, PLC control, DSC, and SCADA is the book written by D. Chanchal et al. This book deals in detail with the industrial sector of automation and its applications, IoT, and OPC data exchange between software applications of several manufacturers [5].

The article deals with the simulation design of a robotic workplace created in the Factory I/O simulator software environment. The article presents a workplace design consisting of a 2-axis robotic arm, a panel for PLC control, and two conveyor belts for moving material in a robotic cell. The complete solution of the simulation and control design is presented through a control diagram and individual programmed control blocks. The control program obtained from the created and verified simulation can then be applied to the robot controller in the real operation of the robotic workplace.

2 Literature Review

Simulation tools are widely used in the automation of industrial processes. The simulation facilitates the implementation of engineering activities related to installing and optimizing measurement and control systems of real plants. With increasing use, simulation has become a vital support technology in decision-making, engineering, and operations, covering the entire scope of the manufacturing system. More detailed application use of PLC control is described in the book by author D. Patel [6].

PLC simulation allows writing, running, testing, and debugging PLC programs before commissioning without expensive PLC hardware. PLC simulation software allows you to create a virtual PLC on your computer, which will allow you to design and evaluate the behavior of the control system without any risk to the production process. PLC simulation software can write control programs before the hardware exists and test critical scenarios. PLC simulation software as a training tool helps to understand and learn PLC control issues. Programmers and other workers can use PLC simulation to familiarize themselves with programs and to test changes in a risk-free programming environment. An article by H. Eass et al. presents an architecture based on the RISC-V implementation of a PLC programmable logic controller. The presented architecture uses the flexibility and performance of FPGA to implement PLC. The proposed solution was written based on the created commands and functional blocks on the Altera S5G FPGA development accessory [7]. The book by U. Kumar describes the 4th industrial revolution from its beginning to the present, focusing on increasing the performance, production, and flexibility of the intelligent systems used in production [8]. For PLC simulations in the program, we have several well-known solutions on the market from leading manufacturers, such as Roboguide, Robot Studio, Siemens NX, Factory I/O, and others.

2.1 Roboguide

In 2018, Fanuc launched its offline robotic software platform Roboguide as an implementation tool for its industrial robots. Roboguide combines programming and simulation software to thoroughly plan the distribution and operation of a robot work cell without the presence of the physical work cell itself. Using 3D technology, users can create a virtual representation of the robotic system, program it, and test it by simulating scenarios in a real production environment. Using Roboguide, users can create a replica of their production environment to allow complete application optimization before starting the program. It allows users to identify the most suitable robot for their production process and address any programming errors or inefficiencies in the work cell layout. Once the program is complete, it is possible to upload the created program to a real robotic arm and continue testing it. Roboguide eliminates the need to invest in expensive prototyping. For those with existing systems, Roboguide makes it possible not to shut down operations while a new program is created, as all programming is done outside of the production environment, reducing downtime in the robotic workplace [9].

2.2 ABB Robot Studio

The simulation and offline programming software ABB Robot Studio enables programming robots on a PC to program robots, optimizing the production process and ensuring the training of new workers. For programming, it uses the high-level programming language RAPID, which ABB introduced in 1994.

This tool is built on the ABB Virtual Controller, an exact copy of the real software that controls the robots in the factory. It makes it possible to perform very realistic simulations. ABB Robot Studio does not support the use of the program as simulation software for another program, and it is possible to operate the program through an API interface or shared memory [10].

2.3 Siemens NX MCD

Siemens NX MCD (Mechatronics Concept Designer) allows us to model and simulate the mechanical and electrical components of the machine. MCD extends the classic CAD design functions of NX with a realistic simulation environment in which it is possible to map the effect of physical forces on moving objects. With a functional model of the machine (digital twin), it is possible to virtually test the machine's behavior using a real control program. NX libraries can be used to speed up and standardize the development of NX MCD machine models. With the Kinematics Toolbox, you get an NX library that contains parametric NX MCD models for kinematics. You simulate your original SIMATIC S7-1500 T-CPU control project on a virtual CPU with PLC SIM Advanced [11].

3 Research Methodology

Factory I/O is a 3D simulation software designed to simulate automation technologies developed by Real Games. Using the internal library of industrial components and equipment, it is possible to create a virtual layout of the entire factory. Factory I/O features many scenes inspired by typical industrial applications, suitable for beginners to advanced users as determined by the difficulty level. The most common use of Factory I/O is as a training platform for PLC machines since PLCs are the most common control units in industrial applications. Factory I/O can also be used with physical microcontrollers, e.g., SoftPLC, Modbus, and many other technologies. The implemented design of the 2-axis robotic arm consisted of several steps related to its integration into the simulation scene, the programming of its movements, and the development of steering instructions according to the designed diagram shown in Fig. 1.

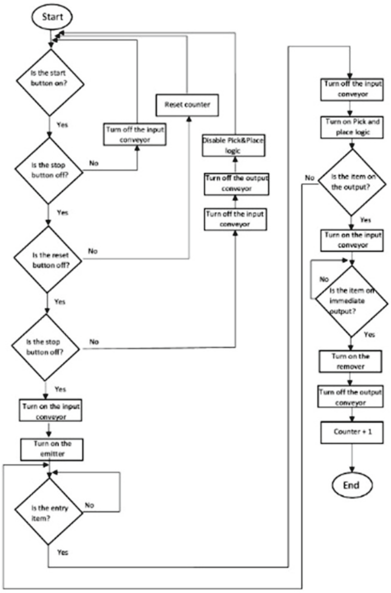

Fig. 1. Development diagram 2-axis arm.

The selected 2-axis robotic arm contains three inputs - a movement sensor on the X-axis, a movement sensor on the Y-axis, and an object detection sensor near the manipulator. It also consists of three outputs: the motor providing movement in the X-axis, the motor providing movement in the Y-axis, and gripping with a suction cup. The created digital inputs and outputs of the PLC are presented in Fig. 2.

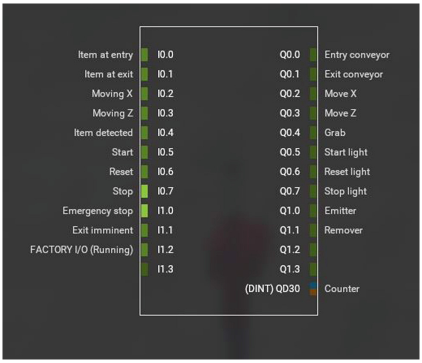

Fig. 2. 2-axis robotic arm inputs and outputs positioned on the PLC.

Conveyor models were first placed in the simulation workplace (see Fig. 3). The settings of the logical operator Emitter, which generates products for the conveyor, and the logical operator Remover, which removes them from the workplace, have been added to conveyors. Subsequently, a 3D model of a 2-axis robotic arm was inserted into the workplace, to which three sensors were connected. The first of the sensors were placed at the entrance of the conveyor near the robotic arm. The remaining two sensors were placed on the output conveyor, the first on the output conveyor near the robotic arm and the second at the end of the output conveyor.

Fig. 3. Creating a robotic workplace in the Factory I/O simulation software.

In the final step, a control panel with Start, Stop, Reset, and Emergency Stop buttons and a display with a counter were inserted into the workplace. Inputs and outputs were then created for the robotic workplace developed in this way on the virtual PLC in the Controllers section. Based on the elaborated flow diagram describing the program's logic, the robotic workplace simulation model will be further programmed and controlled in the individual elaborated control blocks. Control blocks are created in the software environment to control the simulation model's instructions. The functions of individual devices in the workplace and their settings for performing object manipulation are described in more detail on the individual blocks.

The first block describes saving the state value of the Emergency Stop button and storing it in memory. It also describes the button lights. The Stop button does not light up if the lighting is switched on with the Start button. At the same time, the process's start is defined and saved in memory. Control I/O block 1 is presented in Fig. 4.

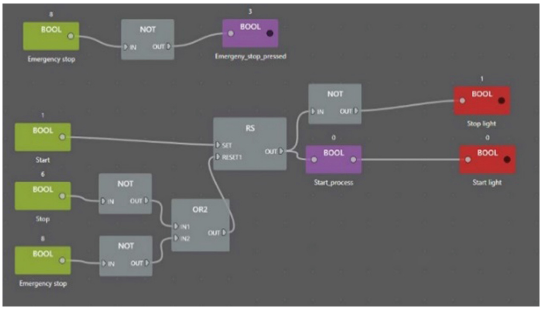

Fig. 4. Control I/O block 1.

The second block ensures the movement of the robotic arm on the Z-axis. The entire process of clamping, moving, and releasing is divided into six steps. All these steps are automatically stored in the Count memory. There is also an End_Cycle_Reset memory unit inserted into the block, which ensures the reset of the cycle, i.e., if we reach step six, the cycle is reset and repeated from the first step. Control I/O block 2 is presented in Fig. 5.

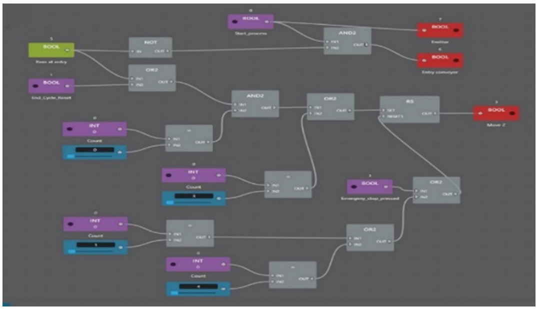

Fig. 5. Control I/O block 2.

The third control block ensures the movement of the robotic arm on the X-axis. While the fifth block specifies when the output conveyor is to be stopped. Control I/O block 3 is presented in Fig. 6.

The fourth block describes when the suction cup at the end of the arm is to be activated while at the same time storing its state value in memory. It then describes when to turn on Remover, which is intended to send a value to the counter about the passage of the product across the conveyor. Control I/O block 4 is presented in Fig. 7.

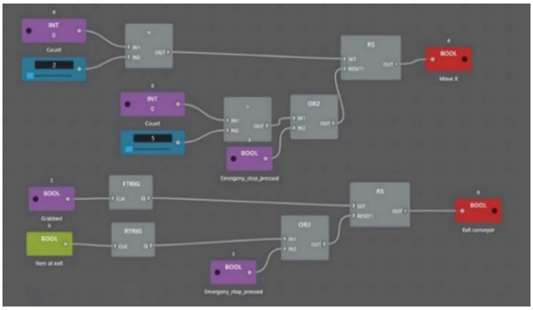

Fig. 6. Control I/O block 3.

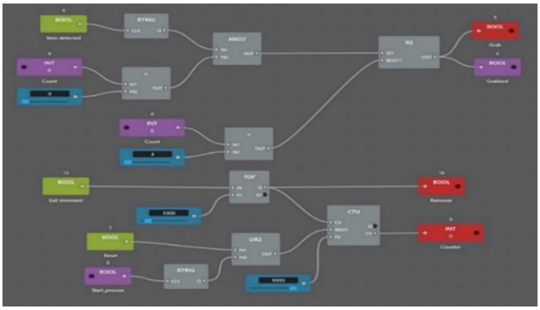

Fig. 7. Control I/O block 4.

The fifth block contains the internal counter dilution, which we reset the whole cycle and, after resetting, has to count again from the beginning. Control I/O block 5 is presented in Fig. 8.

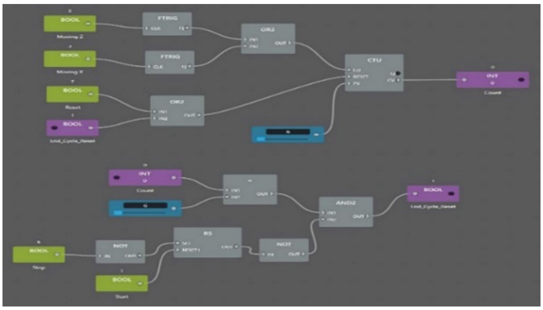

Fig. 8. Control I/O block 5.

4 Results and Discussion

The robotic arm and conveyor controls have been programmed in several development environments. Other control software used included Factory I/O, PLC SIM Advanced V4.0, and TIA PORTAL v17, while the article further presented a proposal in the Factory I/O software environment (Fig. 9).

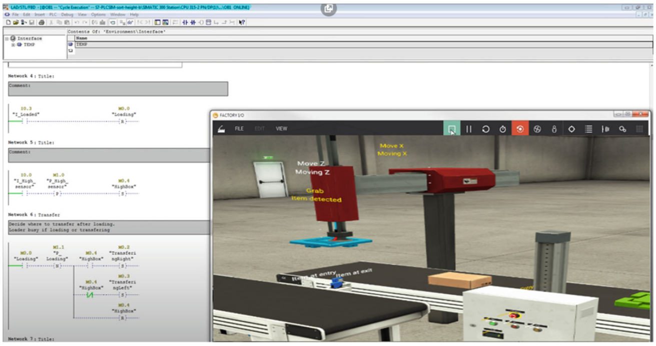

Fig. 9. Simulation of controlling a 2-axis robotic arm in the software environment.

PLCSIM Advanced 4.0 is a software tool for simulating a wide range of PLC functions, enabling complex simulations during configuration and design in the TIA Portal program without a physical connection to the hardware. Using the software, it is possible to simulate several virtual PLCs, either on one PC or several PCs in one network.

Tia PORTAL (with acronyms Totally Integrated Automation) is the development tool for designing, programming, and commissioning all automation instruments and drives from the TIA portal by Siemens.

An example of integrated software is SIMATIC Step 7 and SIMATIC WinCC. Tia PORTAL works as a software environment and combines the functions needed for various automation applications. The applications used in the TIA-portal environment are SIMATIC STEP 7, with which the S7 logic from Siemens can be programmed, and SIMATIC WinCC visualization, which can be used to create remote user interfaces for automation systems. In addition, applications can be connected to the TIA portal, with which it is possible to modify the parameters of the frequency converters and perform automation checks. Currently, version V17 offers an entirely new graphics editor. The programs in these development environments are primarily written in Ladder Logic. To compare usage and work in different software, it can be concluded that while the programmer's work is similar, the development environment itself is different, which is the main difference and, consequently, the programmer's choice for which the instrument is decided. The book "Automating with SIMATIC S7-1200" describes in more detail the application use, configuration, and parameterization of the hardware components of the S7-1200 automation system. At the same time, it focuses on a detailed description of the introduction to work with STEP 7 Basic V11, which illustrates the basics of programming and solutions to real-life problems in production operations with PLC control [12].

5 Conclusions

Smart factories can have a layout of lines, automation machines, products, and other equipment. For a smart factory to be successful, no exact configuration ensures this. Features such as connectivity, proactivity, agility, optimization, and transparency play a key role in the smart factory.

Each characteristic contributes to better decisions and better organization of the production process by individual undertakings. The power of an intelligent factory is directly proportional to the capacity to adapt to growth or changes in the factory. It may include functions such as changing demand for products, penetration of new markets, research and product development, maintenance, or real-time production changes. The use of PLC programming and simulation is currently very wide. This article describes one example of how the robotic arm process can be controlled and simulated by PLC automatons. Available simulation programs support the implementation of an external emulator in a physical way, such as Factory I/O and Siemens PLCSIM emulator, or additional implementation through the API is required. Here, the difficulty in programming is greater, given the system's complexity. The user can also use additional middleware software to communicate between the PLC software and the simulator. Since the current market has a wide range of PLC simulation machines working in a virtual environment, the potential for quick software selection is high.

The article described the design of a simulation model in the Factory I/O simulation software environment. The individual control blocks of the devices used in the simulation were described with an additional explanation of the individual functionalities of the simulation model devices in the manipulation process. As a result of the simulation created, a control program that can be applied to a real robotic operation for handling a 2-axis manipulator and a conveyor controlled by a PLC controller.

In the case of the presented proposal, adding additional ways of controlling the robotic arm to the virtual model developed in Factory I/O would be possible. At the same time, the software supports 15 different ways of control. Another way would be to connect a real physical automaton to Factory I/O, which would not be emulated only virtually. An interesting extension would be a comparison with programming using an alternative simulation program from a robot manufacturer, e.g., ABB Robot Studio or Roboguide from Fanuc.

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References

1. Kiangala, K.S., Wang, Z.H.: An industry 4.0 approach to develop auto parameter configuration of a bottling process in a small to medium scale industry using PLC and SCADA. In: 2nd International Conference on Sustainable Materials Processing and Manufacturing 2019, vol. 35, pp. 725–730. Elsevier Procedia (2019). https://doi.org/10.1016/j.promfg.2019.06.015
2. Papulová, Z., Gažová, A., Šufliarský, Ľ.: Implementation of automation technologies of industry 4.0 in automotive manufacturing companies. Procedia Comput. Sci. **200**, 1488–1497 (2022). https://doi.org/10.1016/j.procs.2022.01.350

3. Brecher, C., Müller, A., Dassen, Y., Storms, S.: Automation technology as a key component of the industry 4.0 production development path. Int. J. Adv. Manufact. Technol. **117**(7–8), 2287–2295 (2021). https://doi.org/10.1007/s00170-021-07246-5
4. Lynch, K.M., Park, F.C.: Modern Robotics: Mechanics, Planning and Control. Cambridge University Press, England (2017)
5. Chanchal, D., Sen, S.: Industrial Automation Technologies. CRC Press, United States (2020). https://doi.org/10.1201/9780429299346
6. Patel, D.: Introduction Practical PLC (Programmable Logic Controller) Programming. Grin Verlag, Germany (2017)
7. Eassa, H., Adly, I., Issa, H.H.: RISC-V based implementation of programmable logic controller on FPGA for industry 4.0. In: 31st International Conference on Microelectronics, pp. 98−102. IEEE, New Jersey (2019). https://doi.org/10.1109/ICM48031.2019.9021939
8. Pascual, D.G., Daponte, P., Kumar, U.: Handbook of Industry 4.0 and Smart Systems. CRC Press, United States (2019). https://doi.org/10.1201/9780429455759
9. Robot Simulation Software | FANUC ROBOGUIDE Simulation Software. https://www.fanucamerica.com/products/robots/robot-simulation-software-FANUC-ROBOGUIDE. last accessed 2023/01/06
10. RobotStudio® Suite. https://new.abb.com/products/robotics/robotstudio. last accessed 2023/01/06
11. Mechatronic Concept Design. https://www.plm.automation.siemens.com/global/en/products/mechanical-design/mechatronic-concept-design.html. last accessed 2023/01/06
12. Berger, H.: Automating with SIMATIC S7-1200. Publicis MCD Verlag, Germany (2018)