ROBOT CELL SIMULATION USING ROBOT STUDIO AND TIA PORTAL

Emerson Jorge de Oliveira Rezende[1] and Marco Rogério da Silva Richetto[1]

[1]Faculdade de Tecnologia Félix Guisard, SENAI/SP, Avenida Independência, 846, Taubaté, 12031-001, São Paulo, Brazil
emersonjor@hotmail.com
marco.richetto@sp.senai.br

ABSTRACT

Modern industrial automation demands efficiency, precision, and flexibility as paramount requirements. Within this context, the integration of Siemens' TIA Portal and ABB's RobotStudio in a simulated environment emerges as a promising paradigm to streamline the programming, simulation, and validation of automated systems. This article delves into the advantages of such integration and its potential to redefine the landscape of automation project design and execution, while underscoring the TIA Portal and RobotStudio application as pivotal catalysts for excellence in industrial automation. The amalgamation of these tools offers an array of benefits, including streamlined development processes, meticulous programming, effective training opportunities, and enhanced performance analysis. Furthermore, it furnishes a secure virtual milieu for algorithm and control strategy testing prior to physical implementation. By gaining access to intricate metrics, bottlenecks can be readily identified and processes optimized preemptively, thereby yielding heightened efficiency and superior production quality. Operational agility attains its zenith as innovative configurations and processes become amenable to testing within the virtual realm. The findings unequivocally affirm that investing in automation accrues substantial benefits to the industry. This approach not only augments production processes but also positions corporations at the forefront of innovation and competitiveness.

KEYWORDS: *Automation; Simulation; Robot Studio; TIA Portal*

I. INTRODUCTION

Industrial automation employing robotics is an increasingly prevalent reality in contemporary businesses, and this trend continues to gather momentum. Leveraging the technological advancements within the industry [1], it becomes feasible to construct a simulation mirroring the authentic functional attributes of a robotized facility. This simulation proves indispensable for ensuring the reliability of the proposed solution, as it permits the dynamic reconfiguration of component layouts, facilitating optimal space utilization, heightened assembly efficiency, and a reduction in the likelihood of errors. Ultimately, these facets collectively contribute to enhanced project robustness [2][3].

Notably, Brazil currently trails behind in technical aspects of industrial automation, predominantly relying on Industry 2.0 methodologies. In stark contrast, developed nations are swiftly progressing into the Industry 4.0 era, fully immersed in comprehensive industrial automation practices. Brazil, however, faces a considerable journey ahead and must intensify its automation processes to remain competitive in the global market [4].

Intense market competition propels companies to incessantly pursue process enhancements and embrace automation and robotics within their production lines. This constant drive for innovation triggers technological revolutions, ushering in an evolution of the industry characterized by ongoing adaptation [5][6]. Key technological pillars encompass robotics, artificial intelligence, simulated environments, neurotechnology, and Internet of Things (IoT) systems, all of which wield substantial economic, environmental, social, and ethical impact. Investing in digital technologies empowers companies to gain a competitive advantage by augmenting operational efficiency [7][8].

The establishment of a simulated environment within the realm of Industry 4.0 signifies an economically prudent innovation strategy, wherein companies can validate their entire products or processes without the need for physical prototypes. During negotiations with customers and partners, this approach enables the demonstration of the advantages of reduced process time and enhanced production by swiftly and reliably adjusting devices, ultimately leading to increased profitability. This practice yields invaluable insights for making well-informed strategic decisions regarding automation systems and future investments. These cumulative advantages culminate in the creation of more efficient, productive, and sustainable industrial processes [9][10].

Furthermore, it is imperative to underscore the significance of risk mitigation concerning accidents, equipment damage, and worker injuries. Simulation not only offers an accurate emulation of real-world scenarios but also facilitates precise analysis of system performance under diverse conditions. Additionally, it serves as an invaluable training tool for operators, technicians, and engineers. Professionals can acquire practical knowledge and expertise within a virtual environment, equipping them to effectively handle real-world industrial automation scenarios [11].

The software currently employed and provided by manufacturers of industrial robots and programmable logic controllers is distinguished by its advanced visualization capabilities of installed components. This functionality ensures an accurate representation of reality, guaranteeing precise component sizing while adhering to space constraints during assembly [12][13][14].

Hence, a project should be devised to encompass a robotic cell seamlessly integrated into an assembly line, coupled with a singular device or computer serving as the conduit for interconnecting two prominent automation software platforms - the PLC-TIA Portal and the ABB Robot Studio. This strategic approach facilitates the holistic analysis of all applications, enabling concurrent data exchange between these software ecosystems within a simulated environment. The overarching objective is to ensure the seamless functionality of program logic, encompassing the exchange of input/output signals, the precise execution of operational sequencing, and interactive communication with the application operator. This methodology allows for comprehensive testing of all applications through data interaction between these two software components, concurrently, within a simulated environment.

II. METHODOLOGY

This study introduces and assesses a simulated environment designed for data exchange among automation simulation software. The development process employed three distinct software platforms within a simulation and robotic integration framework, as depicted in Figure 1. These platforms encompassed the programmable controller and operator interface, RobotStudio - ABB robot, NetToPLCSIM - Communication software, and TIA PORTAL – PLC.

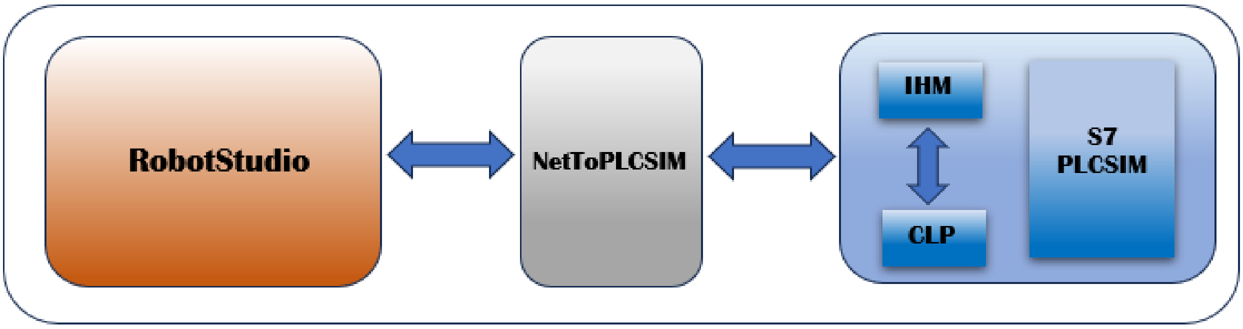


Figure 1. Block diagram of software interconnection

ABB RobotStudio stands as a preeminent simulation software, widely acknowledged for its multifaceted applications in the field of robotics. Currently recognized as the world's most extensively used offline programming tool, this software empowers programmers to create and manipulate objects, machinery, and structures. It provides a comprehensive suite of tools and functions to facilitate the development of a realistic industrial automation environment. Central to RobotStudio is the ABB Virtual Controller, a software emulation of the ABB robot's control system used in actual production. Code generated within the simulation can seamlessly transition to real-world applications. This program opens doors for conducting ABB robot simulations akin to laboratory experiments across diverse industry sectors [15].

On the other hand, NetToPLCsim V1.2.4.0 serves as a network emulator that augments the capabilities of Siemens PLCs by functioning as an S7-Protocol converter. It effectively enables connections to various monitoring systems. Through the features offered by NetToPLCsim, communication links can be established between PLCSim and external software or devices, utilizing standard communication protocols such as TCP/IP (Transmission Control Protocol/Internet Protocol). This functionality facilitates seamless communication between external software and PLCSim, mirroring interactions with a physical PLC. This capability proves invaluable for the development of automation systems, enabling system integration and rigorous testing [16]. Moreover, this software effectively emulates communication between the network card of the PLC and the robot controller's network card, replicating the entire simulation process while adhering to the computer's network card settings.

TIA Portal, developed by Siemens, stands as a prominent industrial automation engineering software widely employed for programming, configuration, and diagnostics of diverse automation systems. These systems encompass programmable logic controllers (PLCs), human-machine interfaces (HMIs), drive systems, and various other devices. TIA Portal distinguishes itself by offering an integrated approach to industrial automation, consolidating various programming and configuration tools within a single development environment. This comprehensive software package comprises several modules, including STEP 7 for PLC programming and WinCC for HMI configuration. Across multiple industries, TIA Portal is a preferred choice for automating processes, providing automation engineers and technicians with a more efficient means of project development, testing, and implementation [17].

To elucidate the software modeling process, we devised a foundational program scenario involving the movement of a robot within a robotic cell to undertake two machining operations—one on the right and another on the left. The simulation's primary objective is to showcase the robot's movements in loading specific parts for these machining operations. The PLC's HMI assumes control over various functions, including cycle initiation, right-side production, left-side production, recovery to the home position, and program pausing.

For this project, we selected the SIEMENS CPU 1214C DC/DC/DC as the designated PLC, featuring PROFINET communication in adherence to the IEC 61784 standard [18]. PROFINET, an open communication protocol widely utilized in the industrial sector, is built upon the foundation of Fast Ethernet while retaining Ethernet's original standards concerning addressing, format, frame size, and error detection mechanisms. It is tailor-made for automation applications, implementing TCP/IP protocols. Moreover, PROFINET operates in real-time, facilitating seamless integration with other field networks [19].

A system of signals was devised to streamline the automation control interface, facilitating seamless data exchange between the HMI and PLC, thereby establishing a robust communication link with the robot through RobotStudio. These signals are under the direct control of the operator, who will manipulate them via buttons linked to specific TAGs within the PLC program. These TAGs were initially declared in the PLC TAGs field, as illustrated in Figure 2. Each signal corresponds to a unique button, which the cell operator will utilize for control purposes.

These TAGs function as crucial interface elements that bridge the operating screen and the robot's control signals. The following signals and their associated buttons were implemented:

- Manual/Automatic Button: Governs the operational mode of the production line, enabling manual stepping or automatic production initiation.
- Produce Right: Indicates whether the Machining Right operation is in production.
- Produce Left: Indicates whether the Left Machining operation is in production.
- Stop: Ceases the movement of the robotic cell, robot, and machining devices.

- Start: Resumes production following a pause or stoppage.

These signals and buttons together form an integral part of the control interface, empowering the operator to efficiently manage and oversee the automation processes within the robotic cell.

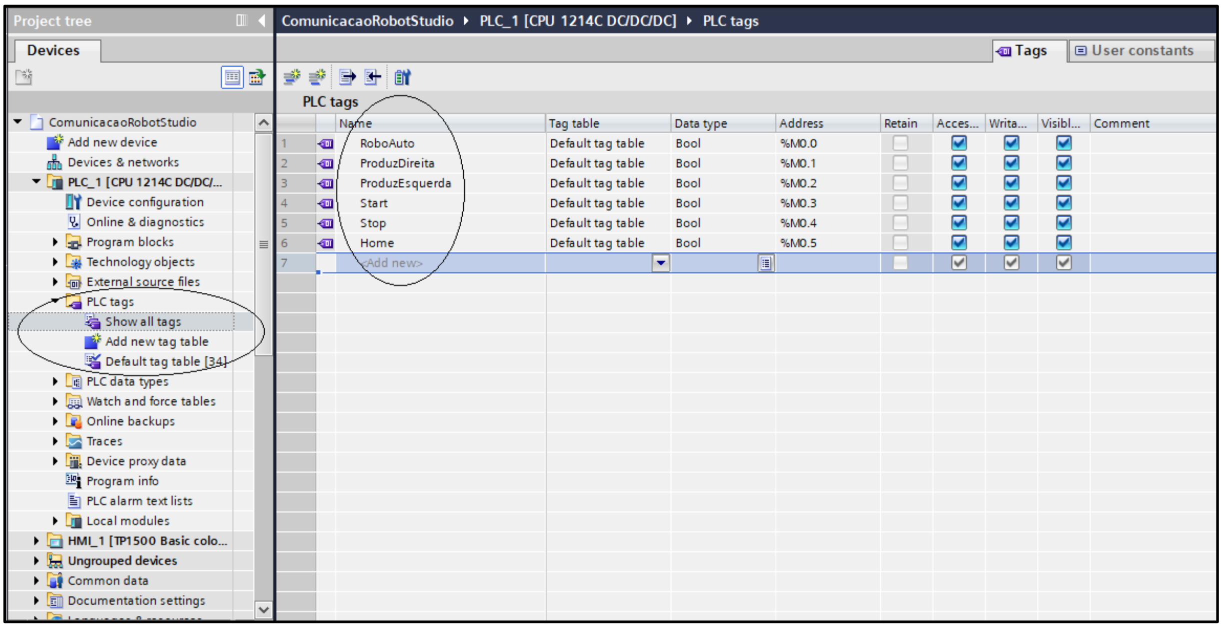


Figure 2. IHM and PLC

Following its operation, the robot is programmed to return to a designated home position and reset all processes, regardless of its prior location. Subsequently, it awaits the initiation of a new production cycle. The aforementioned TAGs incorporate Boolean data, a fundamental component of programming logic employed across various programming languages. This language operates on the binary system, characterized by the values 1 and 0, corresponding to "true" and "false," respectively. The operator maintains complete control over the entire operation through the Human-Machine Interface (HMI). For this project, we have employed the SIEMENS TP1500 Basic Color PN model, as depicted in Figure 3.

The HMI affords the operator the flexibility to test the complete process in manual mode, enabling the execution of each machining operation independently. Alternatively, it can operate in automatic mode, responding to the presence of a workpiece on the conveyor belt. The operator has the liberty to work solely with either the left or right machining operation or opt for both operations to run simultaneously in an alternating sequence upon pressing both corresponding buttons. On the interface, the entire procedure can be halted by clicking the stop button. Additionally, there is an option to commence or resume the cycle by clicking on the start button. The home button is also available, serving to return the robot to its initial position, reinitiate all machining elements, and trigger a fresh production cycle.

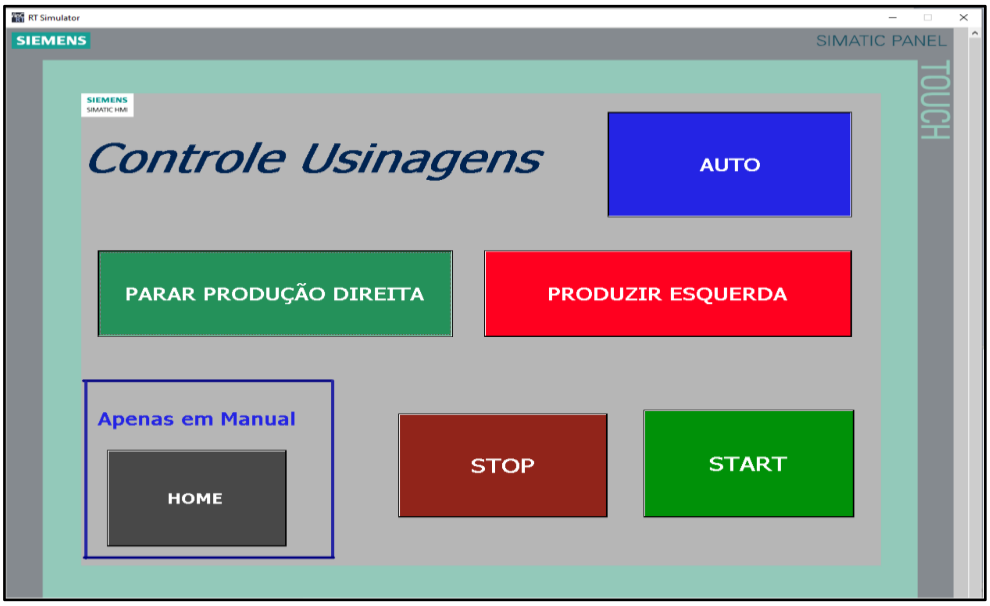


Figure 3. IHM

This HMI affords the operator the flexibility to conduct comprehensive testing of the entire process, offering both manual and automatic modes of operation. In manual mode, individual operations can be executed separately, while in automatic mode, production responds to the presence of parts on the conveyor belt. The operator can opt to work exclusively with the left operation, exclusively with the right operation, or have both operations run automatically, alternating between them by simultaneously pressing both corresponding buttons. On the interface, there are controls to halt the entire process using the "Stop" button and initiate the production cycle or resume it following a stop using the "Start" button. Furthermore, a "Home" button is available, facilitating the robot's return to its initial position while resetting all machining variables to commence a fresh production cycle.

Within the TIA Portal environment, the configuration of the PROFINET network address assumes significance for enabling external communication between the PLC and ROBOT components. The network address adopted aligns with the configuration established for other system components, ensuring seamless integration, as illustrated in Figure 4. This harmonized network setup is essential for the smooth exchange of data and communication among the various components of the automation system.

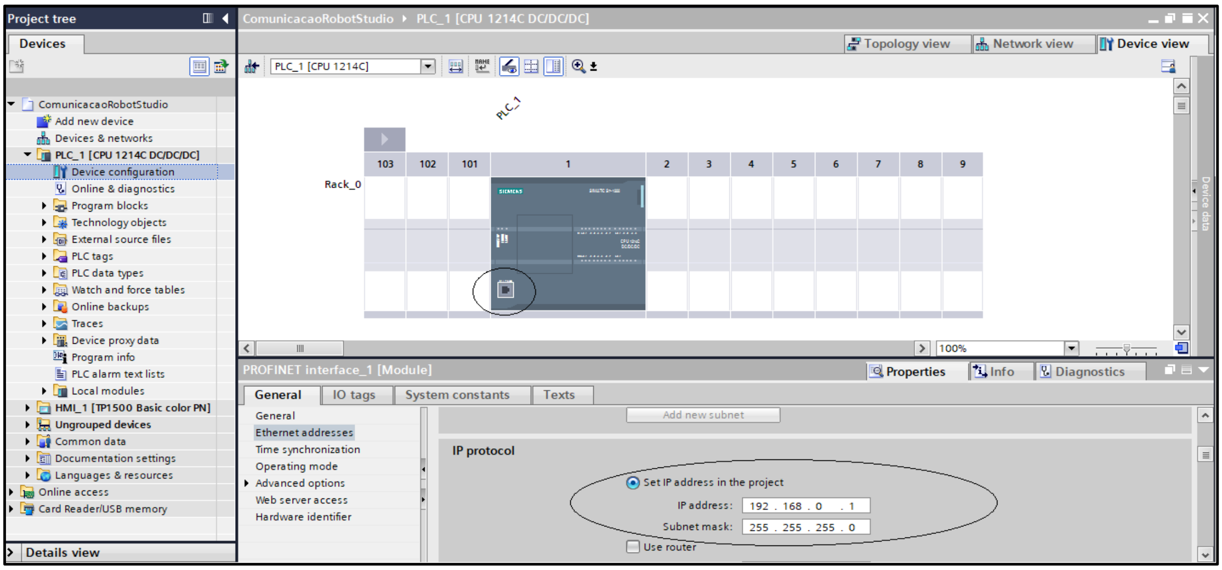


Figure 4. Network addressing

To facilitate external communication with the PLC, it is necessary to activate the security properties by selecting the option that allows PUT/GET access through remote partner communication, as illustrated in Figure 5. This configuration ensures the necessary access permissions for remote communication with the PLC, enabling seamless data exchange with external components and partners.

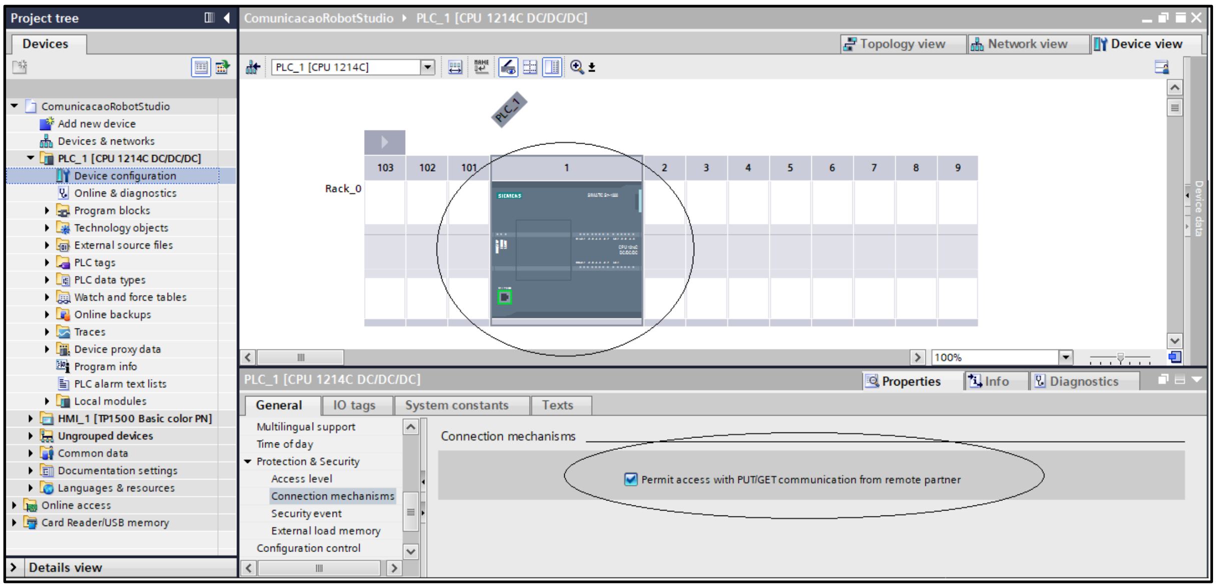


Figure 5. Enable external communication

The NetToPLCsim software serves as a facilitator for communication between two technologies. Before initiating the program, it's imperative to ensure that the TIA Portal's PLCSim simulator makes the IP address of the corresponding PLC visible to the software.

When establishing a new connection, NetToPLCsim will autonomously identify the IP address that was configured on the PLC at the project address, as demonstrated in Figure 6. This automated detection streamlines the setup process and ensures the correct IP address is utilized for seamless communication between the two systems.

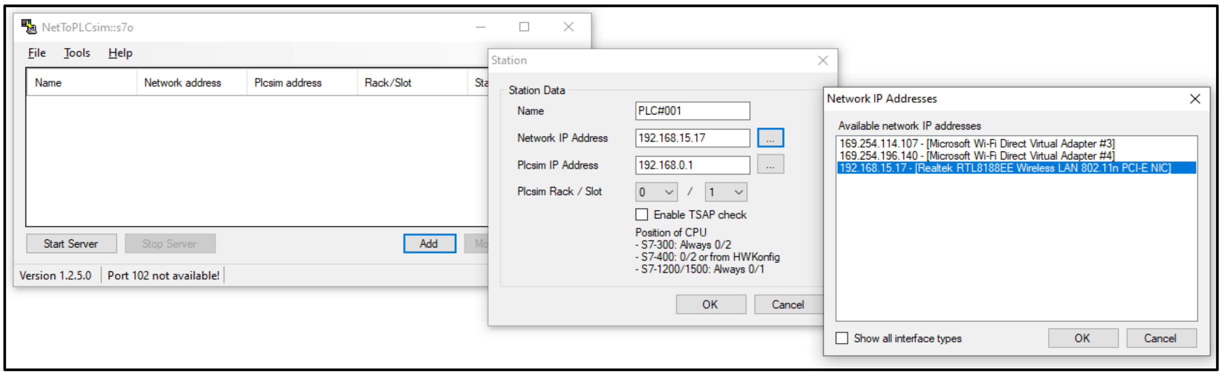


Figure 6. Setting the IP address

Communication is established through the Wireless LAN 802.11n PCI-E NIC Network Adapter, which incorporates a set of drivers responsible for managing the operation of wireless network cards built around the chipset. In this setup, the robot will transmit its communication data to this specific address, with the computer utilizing the IP address 192.168.15.17.

Once the IP addresses are properly configured, as depicted in Figure 7, the software will proceed to establish a virtual connection between the two technologies, enabling the seamless exchange of data between them. This virtual connection serves as the conduit for efficient data communication.

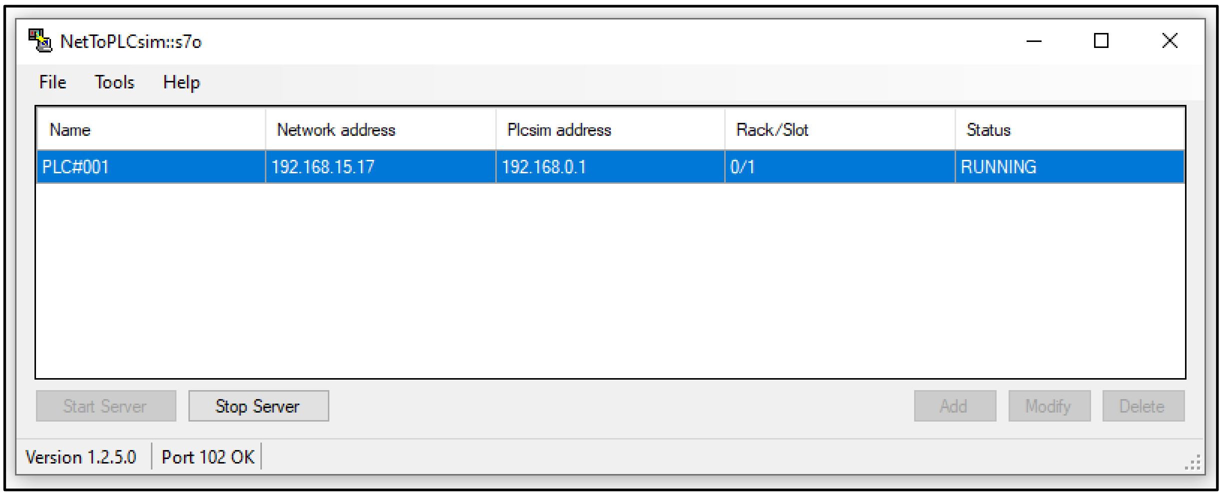


Figure 7. Configuration of Network Interconnections Using NetToPLCSim

Within RobotStudio, an application has been meticulously developed to simulate a production system featuring two machining operations, as illustrated in Figure 8. The primary objective of this application is to enhance productivity by enabling the processing of diverse products while preventing any process interruption in the event of issues with one unit.

In this application, the robot assumes the role of a slave to the PLC. As such, the robot's actions are contingent upon the user's selections made through the cell's Human-Machine Interface (HMI). Depending on the user's choice, the robot executes the desired production process within a specific machining operation. The system initiates by retrieving material from the infeed conveyor, loading it into the designated machining operation, and subsequently waiting until the operation is concluded before retrieving the material once more and depositing it onto the outfeed conveyor. If both machining operations are selected, they are executed alternately, ensuring the continuous flow of production.

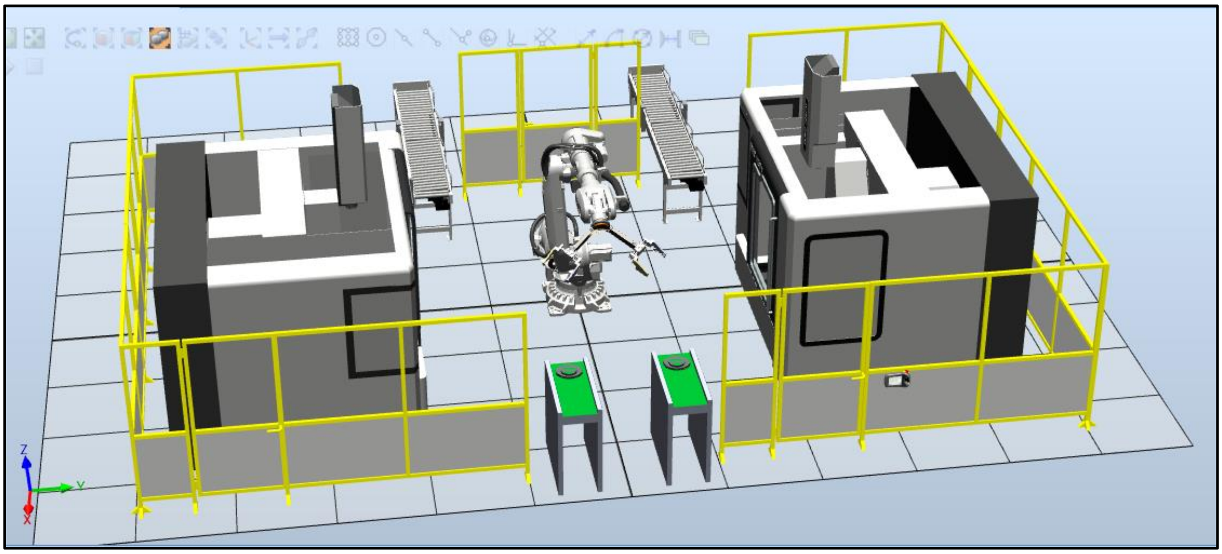


Figure 8. Simulation in

The robot is programmed using the RAPID language, as showcased in Figure 9, tailored precisely for this application's requirements. It operates by communicating IO signals with the machining operations and the input/output conveyor belts while concurrently exchanging signals with the PLC. Within this framework, the programmable logic controller takes on the role of decision-making authority within the robot's programming structure. Consequently, the robot exclusively executes movements and actions in accordance with the directives and authorizations issued from within the operational environment, as dictated by the PLC. This synchronized coordination ensures the harmonious operation of the entire system.

```
            MoveJ HomePos,v1000,z100,G1_Mech\WObj:=wobj0;
        ENDIF
        IF StartSist2 = 1 THEN
            SetDO G2Open,0;
            SetDO G2Close,0;
            rPegaPecaEsq;
            rUsinagemEsq;
            rDeposEsteriaEsq;
            MoveJ HomePos,v1000,z100,G1_Mech\WObj:=wobj0;
        ENDIF
        ENDWHILE
    ENDPROC

    PROC rPegaPecaEsq()
        MoveJ pAproxEsteiraE,v1000,z100,G2_Mech\WObj:=EsteiraEntraE;
        MoveL pPegaEsteiraE,v1000,z100,G2_Mech\WObj:=EsteiraEntraE;
        SetDO G2Close,1;
        WaitDI G2Closed,1;
```

Figure 9. RAPID programming section of the application

Low-code programming empowers developers to invest less effort in managing code syntax, thereby expediting the application creation process and placing a greater emphasis on application functionality. Consequently, it reduces the time spent on problem-solving and implementation. Low-code programming represents an innovative programming concept, and its connections are illustrated in Figure 10. However, it's important to note that the RAPID programming language is employed specifically for controlling the manipulator's movements, involving the use of specialized syntax and English instructions for executing movements, configuring outputs, and reading inputs. This choice is necessitated by the language's limitations in flexibility [20].

In contrast, low-code functionality is exclusively deployed for simulating aspects of the process within a virtual environment. The program encompasses directives for decision-making, iterative instructions, program structure, and communication with the system operator [21].

In the simulation's programming environment, a low-code language is leveraged to expedite the development of applications. This versatile tool streamlines the application creation process, enabling swift coding and effortless visualization through an intuitive graphical interface. It allows software components to be easily dragged and dropped, while workflows can be constructed using arrows without the necessity for extensive traditional coding. This programming paradigm is firmly grounded in the principles of fourth-generation programming languages.

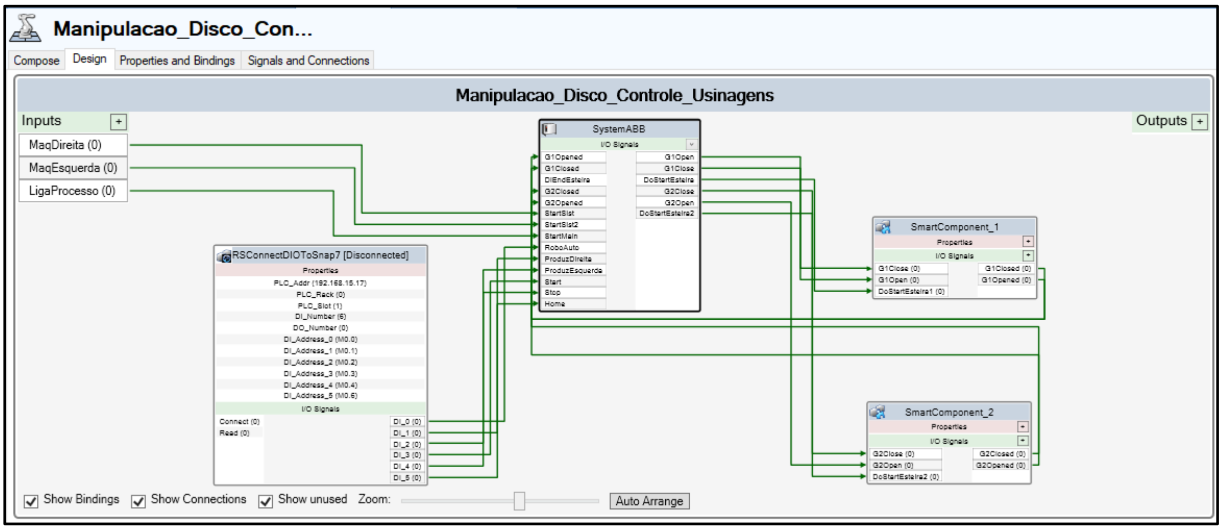


Figure 10. Low-code application creation

SmartComponents have been meticulously developed to manage the simulation of machining operations and associated devices, such as the infeed and outfeed conveyor belts. Specifically, one

SmartComponent is dedicated to each side of the robot. Functioning as subroutines within the simulation software, these SmartComponents serve multiple purposes: they enhance organization, facilitate better comprehension, rectify errors, and allow for programming adjustments within each SmartComponent's code structure. Figure 11 provides an exemplar of one of the two SmartComponents employed in this application.

Each SmartComponent configuration comprehensively encompasses various aspects, including the management of door opening and closing, the creation of components, the connection to the output conveyor, and the handling of parts' disappearance at the conclusion of the simulation. To ensure seamless control, the application has been partitioned into distinct segments, corresponding to the robot's right and left sides, with each SmartComponent presiding over its respective set of operations.

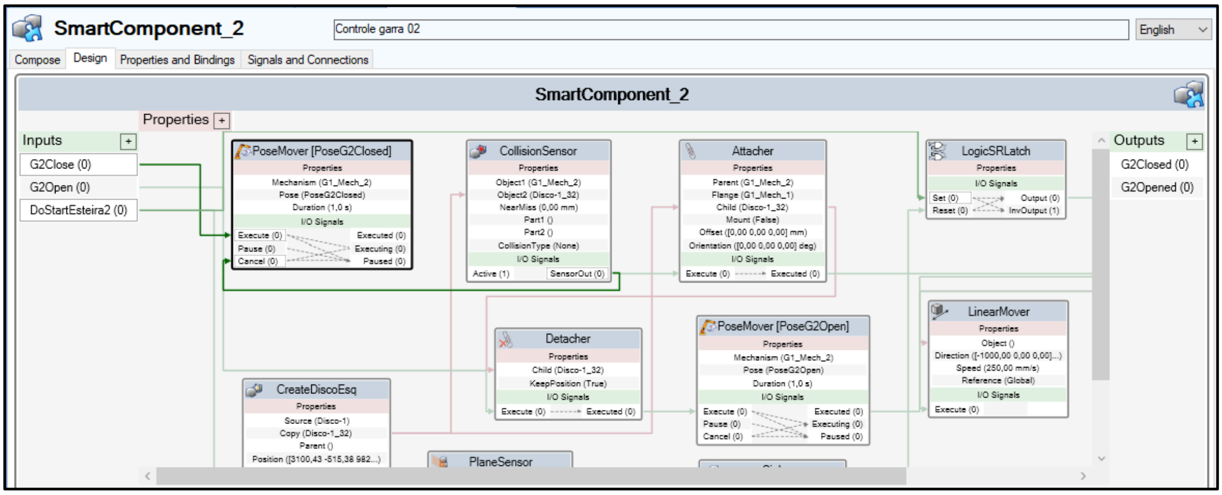


Figure 11. SmartComponent setup

To facilitate configuration and communication between the simulation environments, we employ the RSConnectDIOToSnap7 tool within RobotStudio. This tool is configured with network data to establish seamless communication between platforms, enabling direct communication with the ABB robotic unit for the exchange of signals.

Furthermore, automation components have been meticulously programmed, and the three environments have been configured to facilitate the exchange of signals. This comprehensive setup ensures efficient communication and interaction between the different software components, enabling the seamless operation of the entire system.

III. Results and Discussion

The development of this project has successfully synchronized the actions of the robot and cell devices within the virtual environment of ABB's RobotStudio with programs created in the TIA Portal software. This virtual simulation phase has allowed for optimizations to be made in the TIA Portal code, resulting in improved performance when the real robotic cell is deployed.

In a real-world application, as exemplified in Figure 12, it was possible to entirely replicate the same environment within a simulation, as shown in Figure 13. This simulation encapsulates all the characteristics present in the physical cell, including dimensions, the number of signals, actual cycle times, data exchange, and PLC programming. It has been verified that these software platforms can coexist on a single computer, ensuring the functionality of both. This enriches the simulation experience, as it enables the exchange of data with the PLC while housing all devices within the same computational environment.

Upon analyzing the results, it becomes evident that the integration between RobotStudio and TIA Portal offers a robust solution for simulating and controlling robotic cells. The seamless interaction between these software components, coupled with their adaptability, makes this approach particularly valuable in flexible manufacturing environments. In summary, the exploration of the potential presented by the combined use of RobotStudio and TIA Portal within a simulated environment emerges as an indispensable catalyst for the advancement of industrial automation.

Figure 12. Real application

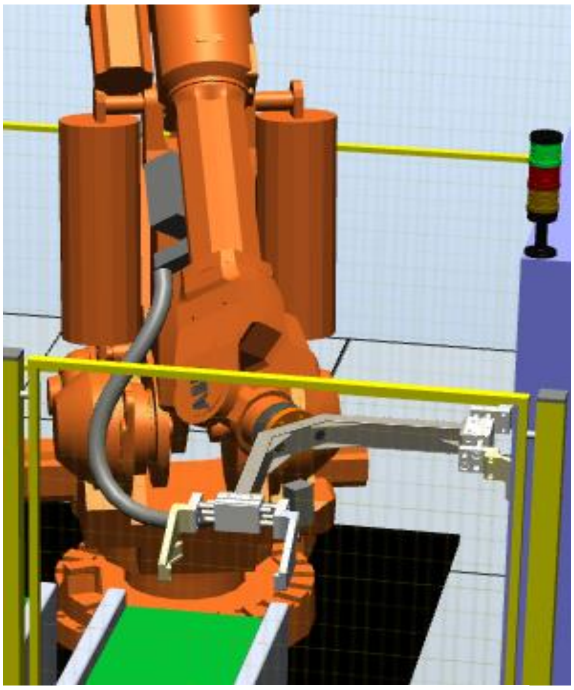


Figure 13. Simulated application

In summary, the exploration of the potential presented by the collaborative utilization of RobotStudio and TIA Portal within a simulated environment stands as a crucial driver for the advancement of industrial automation. Through the adoption of this integrated approach, businesses and industry professionals stand to gain a multitude of significant advantages and advancements in their automation endeavors.

IV. CONCLUSIONS

The successful integration of a virtual environment for the robotic cell and the TIA Portal on a single computer offers significant advantages. It represents a promising approach for the development, testing, and optimization of automation systems. However, it's important to acknowledge the challenges related to hardware limitations, performance optimization, and the delicate balance between realism and efficiency, all of which are critical to achieving satisfactory outcomes.

Utilizing appropriate hardware devices within this integration leads to heightened efficiency, agility, and a reduction in risks associated with the development of robotic solutions. The combination of these tools marks a significant leap forward in the realm of simulation and contributes substantially to advancements in industrial automation. As a result, by embracing interactive simulation between RobotStudio and TIA Portal, organizations can chart a promising path towards operational excellence and continuous innovation, ultimately enhancing their competitiveness within the ever-evolving industrial landscape.

REFERENCES

[1] F. Lima *et al.*, "Digital Manufacturing Tools in the Simulation of Collaborative Robots: Towards Industry 4.0," *Brazilian J. Oper. Prod. Manag.*, vol. 16, no. 2, pp. 261–280, May 2019, doi: 10.14488/BJOPM.2019.v16.n2.a8.

[2] S. Borys, W. Kaczmarek, and D. Laskowski, "Selection and optimization of the parameters of the robotized packaging process of one type of product," *Sensors (Switzerland)*, vol. 20, no. 18, pp. 1–21, 2020, doi: 10.3390/s20185378.

[3] M. A. Funes-Lora, E. A. Portilla-Flores, E. Vega-Alvarado, R. R. Blas, E. A. M. Cruz, and M. F. C. Romero, “A Novel Mesh Following Technique Based on a Non-Approximant Surface Reconstruction for Industrial Robotic Path Generation,” *IEEE Access*, vol. 7, pp. 22807–22817, 2019, doi: 10.1109/ACCESS.2019.2897079.

[4] L. M. YAMADA, Viviane Yukari; MARTINS, “Indústria 4.0: um comparativo da indústria brasileira perante o mundo,” *Rev. Terra Cult. Cad. Ensino e Pesqui.*, vol. 34, pp. 95–109, 2020, [Online]. Available: http://periodicos.unifil.br/index.php/Revistateste/article/view/1011

[5] R. Soares and A. V. R. Lucato, “ROBÓTICA COLABORATIVA NA INDÚSTRIA 4.0, SUA IMPORTÂNCIA E DESAFIO,” *Rev. Interface Tecnológica*, vol. 18, no. 2, pp. 747–759, Dec. 2021, doi: 10.31510/infa.v18i2.1298.

[6] L. Török, “The importance of digitalization and robotization in vehicle production in the European Union,” *Int. Rev. Appl. Sci. Eng.*, vol. 14, no. 1, pp. 125–131, Feb. 2023, doi: 10.1556/1848.2022.00481.

[7] J. A. Fenerick and C. R. Volante, “EVOLUÇÃO DAS INDÚSTRIAS, OS BENEFÍCIOS DA AUTOMAÇÃO E AS PERSPECTIVAS DO MERCADO DA ROBÓTICA NO BRASIL E NO MUNDO,” *Rev. Interface Tecnológica*, vol. 17, no. 1, pp. 734–745, Jul. 2020, doi: 10.31510/infa.v17i1.805.

[8] J. J. Ferreira, J. M. Lopes, S. Gomes, and H. G. Rammal, “Industry 4.0 implementation: Environmental and social sustainability in manufacturing multinational enterprises,” *J. Clean. Prod.*, vol. 404, p. 136841, Jun. 2023, doi: 10.1016/j.jclepro.2023.136841.

[9] G. Lee and Y. Kim, “Effects of Resistance Barriers to Service Robots on Alternative Attractiveness and Intention to Use,” *SAGE Open*, vol. 12, no. 2, p. 215824402210992, Apr. 2022, doi: 10.1177/21582440221099293.

[10] R. Bolla *et al.*, “Adaptive Reliability for the Automated Control of Human-Robot Collaboration in Beyond-5G Networks,” *IEEE Trans. Netw. Serv. Manag.*, pp. 1–1, 2023, doi: 10.1109/TNSM.2023.3298171.

[11] C.-C. Dosoftei, “Simulation Power vs. Immersive Capabilities: Enhanced Understanding and Interaction with Digital Twin of a Mechatronic System,” *Appl. Sci.*, vol. 13, no. 11, p. 6463, May 2023, doi: 10.3390/app13116463.

[12] M. Grethler, J. Ovtcharova, and M. B. Marinov, “Service Prototyping Based on Digital Twins for Virtual Commissioning Scenarios,” in *2020 XI National Conference with International Participation (ELECTRONICA)*, Jul. 2020, pp. 1–4. doi: 10.1109/ELECTRONICA50406.2020.9305142.

[13] A. Martínez-Gutiérrez, J. Díez-González, P. Verde, and H. Perez, “Convergence of Virtual Reality and Digital Twin technologies to enhance digital operators’ training in industry 4.0,” *Int. J. Hum. Comput. Stud.*, vol. 180, p. 103136, Dec. 2023, doi: 10.1016/j.ijhcs.2023.103136.

[14] O. Rosa Junior, T. De Oliveira, and E. Zorzal, “Gamificação e realidade aumentada em processos de ensino-aprendizagem: uma revisão sistemática da literatura,” *Cad. Educ. Tecnol. e Soc.*, vol. 14, no. 2, pp. 262–274, Jun. 2021, doi: 10.14571/brajets.v14.n2.262-274.

[15] A. Caldeiira, A. Faria, R. Barbosa, H. Bras, I. Figueiredo, and A. Gavina, “Engaging Students in Engineering Courses with Mathematics and Robotics,” in *2020 IEEE Global Engineering Education Conference (EDUCON)*, Apr. 2020, pp. 1392–1399. doi: 10.1109/EDUCON45650.2020.9125137.

[16] A. Martins, H. Costelha, and C. Neves, “Shop Floor Virtualization and Industry 4.0,” in *2019 IEEE International Conference on Autonomous Robot Systems and Competitions (ICARSC)*, Apr. 2019, pp. 1–6. doi: 10.1109/ICARSC.2019.8733657.

[17] D. R. Delgado Sobrino, R. Ružarovský, R. Holubek, and K. Velíšek, “Into the early steps of Virtual Commissioning in Tecnomatix Plant Simulation using S7-PLCSIM Advanced and STEP 7 TIA Portal,” *MATEC Web Conf.*, vol. 299, p. 02005, Dec. 2019, doi: 10.1051/matecconf/201929902005.

[18] J. Gao, J. Wang, and J. Xie, “Application of PLC and HMI in the CO2 transcritical refrigeration experimental platform,” *Sci. Rep.*, vol. 12, no. 1, p. 15199, Sep. 2022, doi: 10.1038/s41598-022-19602-w.

[19] N. D. Dien, T. N. Son, P. Van Huy, N. C. Cuong, and R. Van Hoa, “Research And Construction of Solution of Speed Synchrizing for Multiple Motors using Profinet Industrial Communication Network,” *Int. J. Electr. Electron. Eng.*, vol. 7, no. 11, pp. 1–7, Nov. 2020, doi: 10.14445/23488379/IJEEE-

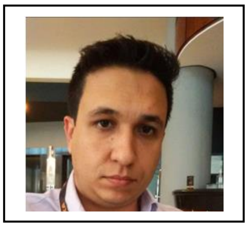
V7I11P101.

[20] R. Waszkowski, “Low-code platform for automating business processes in manufacturing,” *IFAC-PapersOnLine*, vol. 52, no. 10, pp. 376–381, 2019, doi: 10.1016/j.ifacol.2019.10.060.

[21] R. Parameshwaran, A. Tony Thomas, and V. Madhu Vishal, “Vision Based Self Adaptive Algorithm for 6 Axis ABB Industrial Welding Robot,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1123, no. 1, p. 012038, Apr. 2021, doi: 10.1088/1757-899X/1123/1/012038.

AUTHORS

Emerson Jorge de Oliveira Rezende: Has a degree in Electrical Engineering from the University of Vale do Paraíba (2012) and is a postgraduate student in Industrial Automation and Robotics at the Félix Guisard Faculty of Technology - SENAI/SP (2023). His career stands out for his experience in the industrial field, with a focus on articulated robots. Since 2013, he has held the position of maintenance supervisor at Servnews Robótica e Automação.



Marco Rogério da Silva Richetto: Graduated in Telecommunications Engineering from the Taubaté University (2004), master’s degree in Mechanical Engineering from Taubaté University (2007). He has experience in the areas of Analog and Digital Electronic, Robotics and Automation. He has been teaching undergraduate and postgraduate courses at the Félix Guisard Faculty of Technology - SENAI/SP since 2010.