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Simulation of a controlled industrial process with the help of a PLC using augmented reality

Tudor COVRIG[1], **Alexandru CIOBOTARU**[1], **Zoltán GERMÁN-SALLÓ**[2],**Liviu MICLEA**[1]

[1]*Automation Department, Tehnical Universty of Cluj-Napoca, Cluj-Napoca, Romania*

[1]tudor.covrig@umfst.ro

[2]*University of Medicine, Pharmacy, Pharmacy 1 N.Iorga st.,Târgu Mureş 540088, Romania*

[2]zoltan.german-sallo@umfst.ro

Abstract

Industry is a fairly important branch of the economy. Through it, all production activities and processes are managed. It combines different technologies and equipment to optimize these processes. Currently, industry is in its fourth stage. As technological processes become more complex and efficient, new technologies are required to monitor and control them. This article presents a method by which a technological process can be simulated and controlled using real equipment, such as a PLC (Programmable Logic Controller). The main focus of this paper is the use of augmented reality to monitor and control the process remotely. By implementing this solution, different scenarios can be tested, and the simulated process can be monitored and controlled using various technologies, highlighting the advantages of augmented reality in industrial applications.

Key words: PLC, OPC, HMI, augmented reality, industry 4.0, process simulated

1. Introduction

Nowadays, most systems use automation, with the goal of minimizing human intervention in processes as much as possible. However, Industry 4.0 is not just about automation but also about how various concepts and technologies, in addition to automation, are used to improve industrial processes. All these elements combined form the idea of Industry 4.0. This concept represents the stage where the industry and the automation of industrial processes have evolved. A fundamental element used in the automation of technological processes is the Programmable Logic Controller (PLC). Through PLCs, various applications can be developed, and different procedures for monitoring and controlling processes can be implemented. To bring about improvements in process automation, it is necessary to use various equipment and technologies. To safely and efficiently test the behavior of a technological process or equipment, the use of specific process simulators is necessary. Besides their testing role, these simulators can also serve as tools for learning and training users of industrial equipment.

An efficient solution that can be used to test these concepts and principles is the ProSimT+ process simulator. This software contains various simulations of industrial processes that can be controlled via a PLC. For remote monitoring and control of the process, augmented reality technology is used. Augmented reality is a technology that allows for real-time visualization and interaction with industrial processes. This technology enables remote monitoring and control, reducing the need for physical intervention and increasing operational efficiency. The communication protocol used for transmitting data between augmented reality equipment and the PLC is OPC (Open Platform Communications). For the development of the OPC client, Unity software is used. With this software, an application can be created that allows data from the PLC to be accessed directly from the augmented reality equipment without the need for additional intermediary software. Thus, augmented reality is a fundamental technology that facilitates easy access to the operational data of an industrial process.

The application developed using augmented reality technologies enables accessing data related to the operation of the simulated process, monitoring this process, and controlling it. Consequently, through this software, operational data can be accessed remotely. By using the OPC communication protocol, data is secured through encryption, leveraging the protocol's data encryption feature. Additionally, the communication protocol supports authentication for data access. For local monitoring and control, an HMI (Human-Machine Interface) is used.

The paper is structured as follows: the second section presents the state of the art in the field, the third section presents the application design, the fourth section details the application implementation, and the fifth section interfaces the obtained results. The final section presents the conclusions.

2. The state of the art

Automation system are combinations of various pieces of equipment through which specific processes can be carried out automatically. They represent sets of interconnected and coordinated components that work together to achieve particular requirements and tasks. According to [1], the most critical aspect of automating a process is the PLC. With its assistance, specific processes can be executed, and technological systems can be monitored, and different commands can be issued. As presented in [2], automatic systems can be closed-loop control systems, and if faults occur, specific decisions can be made to rectify the system's condition. Automatic systems can be utilized across various domains and in conjunction with different technologies. The most commonly used equipment in automation is the PLC [3]. Through this equipment, various automation processes can be carried out. Additionally, the PLC can be utilized to command-and-control various process simulations aimed at testing specific operating conditions in a safe manner. An example can be found in the paper [4], where a 3D simulator has been developed. With this simulator, different object can be manipulated using a robotic arm. The communication protocol used in this work is TCP/IP. The purpose of the simulation in this case is to verify different developed algorithms. Another piece of equipment that can be used in conjunction with the PLC is the HMI (Human-Machine Interface).

In paper [5], a technology is presented that utilizes PLC and HMI to regulate temperature. To adjust the temperature, the PLC controls a servomotor that adjusts the heating angle. A PT100 sensor is used to measure the temperature, and all data are displayed via the HMI. The technology used to interface with industrial processes is WinCC. Through it, various simulations of industrial processes can be performed. An example can be found in the paper [6], where an interface is presented to monitor and control a silo. Data are collected through sensors and sent to the PLC, and depending on their values, certain decisions are made. Another example of the use of these technologies can be seen in [7]. It demonstrates how PLCs can control various industrial processes, such as mining machinery. The data interface component is realized using WinCC technology and displayed on an HMI. To conduct different simulations of industrial processes, technologies such as SCADA, JavaScript, LabVIEW, and CODESYS can be utilized. An example of SCADA technology's use is an automatic system that controls the level [8]. This project presents a simulation of a system that controls the level via a PLC. The process interface is realized through an HMI. The system utilizes sensors as inputs, which detect the maximum and minimum levels, a level-regulating valve, and as outputs, it employs a pump and an alarm activated based on the reached level.

Another approach to simulating an industrial process and its control with a programmable logic controller is presented in [9]. The simulator designed in this paper employs a single block for performing several simulations depending on the user's requirements.

The implemented system comprises three parts: PLC, I/O panel, and representation panel. The primary control of this simulator is achieved through the PLC, which facilitates the realization of command-and-control parts through input and output signals. Another application using WinCC can be found in the paper [10], where a system is introduced for monitoring grain silos, commanded and controlled via a PLC. Data collected through the PLC include pressure, deviation values of conveyor belts, positions of elevators, and positions of motors. Through the HMI interface, various commands can be issued, the operating mode selected, and system parameters monitored. Another development environment that enables various applications to be realized is CODESYS. This simulator allows testing and implementation of different programs. An example of such a project is presented in the paper [11]. In this project, a production line consisting of several processing stations and a conveyor belt is described. The process control and command are performed by a programmable logic controller, and data is exchanged between Factory IO and CODESYS via an API (application programming interface). Factory IO is simulation software that enables the design and implementation of an automation process without damaging the equipment. Another software used for various simulations of industrial processes is LabVIEW. It is an application development environment utilized to control and automate industrial processes and control systems. An example project is showcased in the paper [12], which depicts a simulation of an industrial process in a factory. The system includes a programmable logic controller that controls the simulated process and the simulation created in LabVIEW. The process involves several tanks used for storing, mixing, and storing the final product. In addition to these solutions, other software can be used to simulate different technological processes, such as EasyPLC [13]. This software solution is used for programming and controlling automation systems, allowing control of industrial devices and systems. It provides a graphical programming environment with a set of instructions and various functional blocks that together form the control program. Communication between the software and the programmable controller is carried out via the Ethernet communication protocol. EasyPLC offers the capability to monitor and diagnose the control system using a debugging tool. It enables users to track the status of variables, analyze error messages, and simulate the operation of the system, finding application across a wide range of scenarios.

The structure of this simulation environment is outlined below. For the communication part, the OPC (Open Platform Communication) protocol is utilized [14]. This paper explains the basic principle of this communication protocol and how the connection between the OPC client and OPC server can be established to facilitate data exchange between elements.

Thus, through this communication protocol, data can be interactively accessed. Another technology that can be used to monitor the evolution and state of a simulated industrial process is augmented reality [15], [16]. This technology finds application in various processes such as maintenance and repair, documentation of equipment operation, collaboration, and communication. By integrating augmented reality into industrial processes, it can offer various advantages, fostering innovation and efficiency [17].

3. Proposed system

The proposed research methodology serves as a solution for simulating an industrial process. The system developed within this project comprises multiple elements facilitating data access and control over the simulated process. These components fulfill the command-and-control requirements of the simulated process. The system encompasses both hardware and software elements. Figure 1 illustrates the architecture of the proposed system.

Through the architecture presented above, the PLC controls a simulation of an industrial process, represented by the ProSimT+ software. The local data display component is realized through the HMI, containing various commands and details related to the operation of the process in question. For remote process control and monitoring, a dashboard is utilized, realized with the assistance of virtual reality. All data concerning the operation of this simulation is stored in a database, facilitating analysis. Monitoring for communication and potential errors is provided by the Wireshark software, which analyzes data packets and their transmission times.

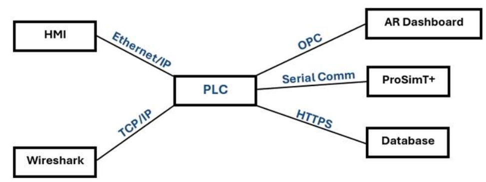

Fig. 1: System architecture

Several hardware and software resources are employed in this project. The primary component is the PLC, utilizing the S7-1215 DC/DC/DC model to realize the application, overseeing the monitoring and control of the process. The next crucial component is the ProSimT+ process simulator. This software emulates a real industrial process, with sensors connected to inputs and actuators connected to outputs. Inputs and outputs conform to industry standards, with digital inputs operating at 24V and analog inputs ranging from 0-10V. Local monitoring is facilitated via the HMI, employing the TP700 Comfort model in this project, designed to streamline equipment interaction. Augmented reality is employed for remote monitoring and control, with the interface designed and implemented using Unity software, and interfaced through augmented reality glasses, specifically the HoloLens 2. This interface functions similarly to the HMI. Communication between the PLC and the monitoring and control interface is executed using the OPC communication protocol. Network analysis is conducted via the Wireshark software, an open-source tool utilized for network analysis to identify potential communication errors between equipment.

To implement this application, it is necessary to configure and parameterize the components used within it. For communication between the PLC and HMI, it's essential to ensure they are configured to operate within the same network. This step is crucial to ensure the proper functioning of the equipment. Achieving communication between the PLC and the augmented reality glasses involves using the OPC communication protocol. Through Unity software, the augmented reality command and control interface is created, incorporating the OPC client. Figure 2 illustrates the user interface and how it is implemented in Unity. As depicted in Figure 2, the application comprises several buttons enabling various commands, such as starting or stopping the process, selecting the process operation mode, transitioning between steps in manual mode, and a brief description of the application's functionality is provided on the right side.

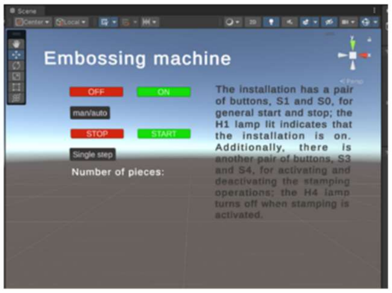

Fig.2: Augmented reality application

Implementing this OPC client requires installing a library package, specifically Opc.UaFx. With this library, a function can be created to facilitate reading from or writing to the PLC. The function accesses a series of variables shared by the PLC, modifying their states based on the issued commands. For PLC connection, a URL variable is utilized, containing the PLC's IP address, communication protocol, OPC, and communication port. The following algorithm outlines the communication process between the PLC and the augmented reality glasses:

```
`client` ← `OpcClient`
Function `Start`:
`opcUrl` ← "opc.tcp://192.168.0.5:4840"
 `client` ← `OpcClient(opcUrl)`
  `client.Connect()`
        End_function
Function `ButoonPressed`:
`tag1`← "ns=4;i=2"
`tag2`← "ns=4;i=4"
`tag3`← "ns=4;i=6"
 `tag4← "ns=4;i=7"
`client.WriteNode(tag1,tag2,tag3,tag4, true)`
        End_function
Function `DisableButtonPressed`:
 `tag5` ← "ns=4;i=3"
 `tag6` ← "ns=4;i=5"
`client.WriteNode(tag5,tag6 false)`
        End_function
Function `Update`:
`tag7` ← "ns=4;i=8"
 `client.WriteNode(tag7, `number`)`
End_function
```

Thus, the developed application allows for data exchange between the PLC and the augmented reality interface using the OPC communication protocol. This is made possible thanks to the OPC library utilized within the Unity function. By leveraging these components, data can be accessed without the need for additional intermediary components. Other methods of communication with augmented reality devices require more intermediary elements and the use of much more complex functional blocks.

4. Project implementation

The application demonstrates the operation of a punching machine, controlled by a valve that regulates a piston cylinder. The technological setup includes several buttons enabling various commands.

The primary buttons are the start and stop buttons, initiating or halting plant operation. The status of the installation is indicated by several LEDs, illustrating whether the application is off, on, and its mode of operation—automatic or manual. In manual mode, each system operation is triggered by pressing the S5 button. Each step in the process is activated manually, provided the preceding step is completed. After completing the process, pressing the button initiates the process anew.

The process continues automatically until the stop button is pressed. Operations performed by this simulated process include releasing a part, activating a piston to push the part to the clamping position, clamping the part for 3 seconds, and dispatching the clamped part to the collection container via an air jet. Additionally, the system may include safety features to prevent accidents or damage to equipment, such as emergency stop mechanisms or sensors to detect obstructions. Figure 3 displays the ProSimT+ software interface, which provides a user-friendly platform for monitoring and controlling the simulated process. This interface may offer features such as real-time data visualization, historical data logging, and diagnostic tools to analyze process performance. Moreover, the software interface may allow users to adjust process parameters, set operating modes, and troubleshoot any issues that arise during operation. Overall, the integration of advanced simulation software like ProSimT+ enhances process efficiency, safety, and flexibility in industrial settings

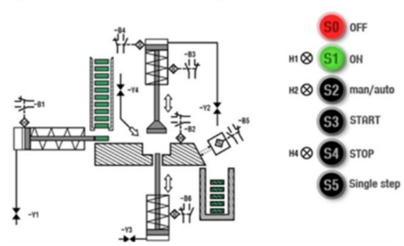

Fig.3: Embossing process

As observed in Figure 3, the simulated process consists of several components. The automation of the process is achieved through these elements. The operation of the process is as follows: a cylinder with a piston, operated by pneumatic valves, pushes a part. This part is then stamped by compression and subsequently moved by another cylinder. Finally, an air jet sends the stamped part into storage. All actuations within the technological installation are pneumatic. To determine the stage of the process, the installation has multiple sensors that detect the presence of the parts. Through these sensors, the stage of the technological process can be determined. All these sensors are connected to the physical inputs of the PLC. Additionally, buttons that control the operation of the process are also connected to the inputs. For the pneumatic actuation part, various valves are used to operate pneumatic pistons. These are connected to the PLC outputs. Thus, through this simulator, physical inputs and outputs can be used to control and monitor various industrial processes.

The HMI is utilized for local monitoring and control. Through this interface, details of the process operation can be monitored, and various commands can be issued. These commands function similarly to those in the process simulator. Figure 4 illustrates the structure of this interface.

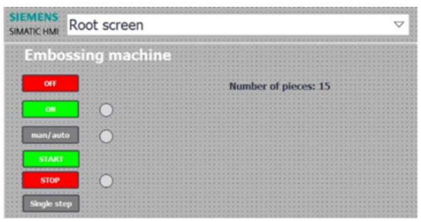

Fig.4: HMI interface

Augmented reality technology revolutionizes monitoring and control by seamlessly integrating digital interfaces into the physical workspace. It interfaces with a platform structured similarly to HMI interface, featuring buttons enabling various commands and providing details of the simulated process operation. This interface not only allows users to access additional information about the operation of the simulated industrial process but also enhances use interaction by overlaying digital information onto the physical environment. Through augment reality, users can visualize virtual representations of equipment components or process parameters. Figure 5 display the interface.

Fig.5: Augmented reality interface

5. Results

With this application, it is possible to monitor and control a simulation of an industrial process using automation equipment that is utilized in a real factory. Through this application, it is possible to test the functioning of a technological installation safely. The OPC communication protocol is utilized to establish communication between the PLC and the augmented reality interface, enabling data transfer. The system topology includes several elements: HMI, PLC, PC, and augmented reality glasses. A router is employed to interconnect them. Consequently, communication between HMI, PLC, and PC occurs via Ethernet, while wireless communication is utilized to connect the PLC to the augmented reality equipment. Figure 6 depicts a diagram illustrating the frequency of data transmission between the devices.

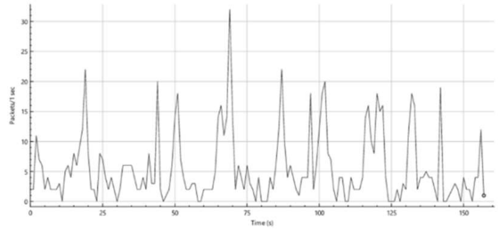

Fig.6: Communication between devices

As shown in Figure 6, different data packets can be captured, and the data traffic between the PLC and the augmented reality glasses can be monitored using the Wireshark software. This allows for detailed analysis of the communication protocols and data exchanges occurring in real-time. It is particularly useful for troubleshooting and optimizing the interaction between the PLC and the augmented reality glasses. Additionally, Wireshark provides insights into potential security vulnerabilities and performance bottlenecks in the system.

6. Conclusions

Integrating cutting-edge technologies such as augmented reality and HMI into the monitoring and control of an industrial process brings with it a number of important benefits and implications. Using augment reality and HMI, users benefit from intuitive and interactive interfaces that facilitate real-time monitoring and control of the industrial process. With augmented reality, users can visualize and interact with elements of the industrial process in their physical environment, while HMI provides a graphical and interactive interface on device screens. This approach offers an advanced means to swiftly monitor and diagnose the industrial process, simplifying the identification and effective resolution of problems. Efficient communication with the PLC via the OPC protocol ensures reliable data exchange between the various components of the industrial automation system. Thus, the integration of augmented reality and HMI contributes to process optimization and increased operational efficiency by providing real-time information and control tools. Additionally, this integration can facilitate collaboration between operations and maintenance teams, fostering a deeper and faster understanding of the process and potential issues. By utilizing AR and HMI together, more intelligent management of the industrial process can be achieved, enabling quick adaptation of settings and parameters based on changes in the production environment or specific operational requirements. This can result in reduced downtime, increased productivity, and enhanced product quality. Consequently, this advancement in industrial automation represents a significant stride toward enhancing performance and productivity across various industrial sectors.

In conclusion, the integration of these modern technologies offers a comprehensive and innovative solution for industrial process management, underscoring the importance of embracing new technologies to meet the intricate demands of modern industry.

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