

STUDY AND IMPLEMENTATION OF INDUSTRY 4.0 CONCEPTS INVOLVING PROFINET NETWORK AND SCADA SYSTEM WITH MOBILE ACCESS AND AUGMENTED REALITY APPLICATIONS

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ABSTRACT. *This study presents an applied research on industrial automation. It proposes to understand and implement a real industrial application approaching the concepts of Industry 4.0, including industrial networks, SCADA system, mobile applications and augmented reality. A practical application was developed to control a section of an aluminum can manufacturing industry. The system counts with sensors, actuators, and programmable logic controllers, which develop the functions related to the industrial machinery. These controllers exchange data through an industrial network and this information is stored in an SQL database. It is possible to both monitor and act on the controllers using a supervisory system or a web-based application, simultaneously. Using the QR codes it is possible to visualize the production and speed of the machinery, utilizing augmented reality through an application.*

Keywords: Augmented reality, Database, Industry 4.0, Mobile access, PROFINET network, Programmable logic controller, SCADA system

1. **Introduction.** In an industrial context, it becomes evident that technologies that aim at production growth, better device communication, and big data storage are evermore used. The term Industry 4.0 stands out in this environment of changes in the production process. According to [1], the concepts of this term can be understood through its impacts; therefore, simulated scenarios can prove themselves valuable as tests for Industry 4.0.

A relevant factor in the industrial automation context is the Programmable Logic Controller (PLC) which is capable of storing instructions and implementing logical control functions. Supervisory Control and Data Acquisition (SCADA) systems are also significant as they are capable of locally or remotely monitoring and processing data in real time. A data storage technology as relational databases where Structured Query Languages (SQL) are commonly used, can complement these technologies. Finally Augmented Reality (AR) is a term used for overlaying computer-generated graphics, text and Three Dimensional (3D) models over images of the real scene, as [2] explains.

This paper's goal is to present an Industry 4.0 scenario, involving recent technologies in the industrial context emphasizing the methods to make all the necessary interactions. Therefore, this paper presents in Section 2 concepts of the employed technologies. Section 3 explains the context where the system was supposed to be employed. Section 4 presents the real application developed and Section 5 presents the assembly of the system developed with all the equipment used and the results of the communication that integrates an

industrial network, a SCADA system and mobile systems, showing the operation of the data treated in this process. Finally, Section 6 features the conclusions for the project.

2. Theoretical Fundamentals. The concepts used are divided into industrial network commissioning, development of storage and supervision systems and development of remote systems for the visualization of information contained in databases.

2.1. PROFINET industrial network. The PROFINET protocol is the open Industrial Ethernet standard of PROFIBUS & PROFINET International (PI) for automation. It is specified by the IEC 61158 and IEC 61784 standards and it originated from Industrial Ethernet, by using the standards of the Transmission and Control Protocol/Internet Protocol (TCP/IP) and Information Technologies (IT). Its access methods are TCP/IP, Real-Time (RT) and Isochronous Real-Time (IRT) [3, 4]. In a PROFINET network, the amount of data that can be delivered per frame is 1440 bytes. This frame is based on a full-duplex Ethernet network of 100 Mbps speed and provides information over the data credibility, the redundancy, and diagnose state, also being able to use high transmissions rates [5, 6]. This frame is shown in Figure 1.

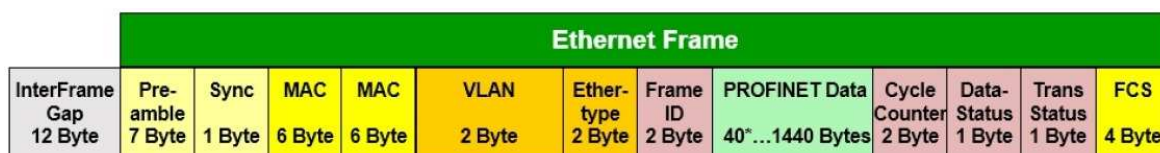


FIGURE 1. PROFINET telegram

2.2. SCADA systems. With the goal to monitor and act over the process, these systems are composed of hardware and software. The hardware is made up of Remote Terminal Units (RTU) and/or PLCs, responsible for gathering data and controlling other field devices. The software relies on the presentation of the data through interfaces [7].

According to [8], a SCADA system can be defined by

- Process data acquisition: involve the gathering and transmission of data from the devices. Upon a request, the SCADA system receives the stored data from a PLC or an RTU and it can store them in a database.
- Data access: the stored data can be presented via Human Machine Interfaces (HMIs), granting the visualization of charts and histories. The system can make projections and tendencies over the obtained data over time.
- Alarms and events: the system can be configured to generate alarms, therefore, granting more safety to the process. These alarms can show severity, the need for user recognition, and detailed information of the event.

2.3. Databases. These are places where information is stored. It usually has administration platforms, known as Database Management Systems (DBMS), which allow all management. Information retrieval is done using SQL commands that allow the insertion or reading of stored values [9].

2.4. Mobile access and augmented reality. Eclipse Mobile is a tool capable of safely accessing and modifying parameters from any location, integrating with the SCADA Eclipse E3 system and collecting data from the database. It is possible to limit it only to access on the local network without using the Internet [10]. AR can be used through the development of software for identifying surfaces or images and projecting texts, indications or three-dimensional objects.

3. Scenario in Analysis. An industrial process of aluminum beverage cans was proposed. Figure 2 features the machinery involved in this process. The developed application is focused on the synchronization of the extrusion of cans and its trimming, executed by Bodymakers and Trimmers. To represent the movement and extrusion of the Bodymaker, a pneumatic system was employed, with a 3 × 2 valve and a simple action actuator. For the reproduction of the Trimmer’s main shaft position and its rotation, a motor associated with a frequency inverter as well as luminous indicators. Failures situations were also analyzed, which are Short Can (failed extrusion), Jam (jamming of the trimmer) and a lack of cans in the infeed tower of the Trimmer.

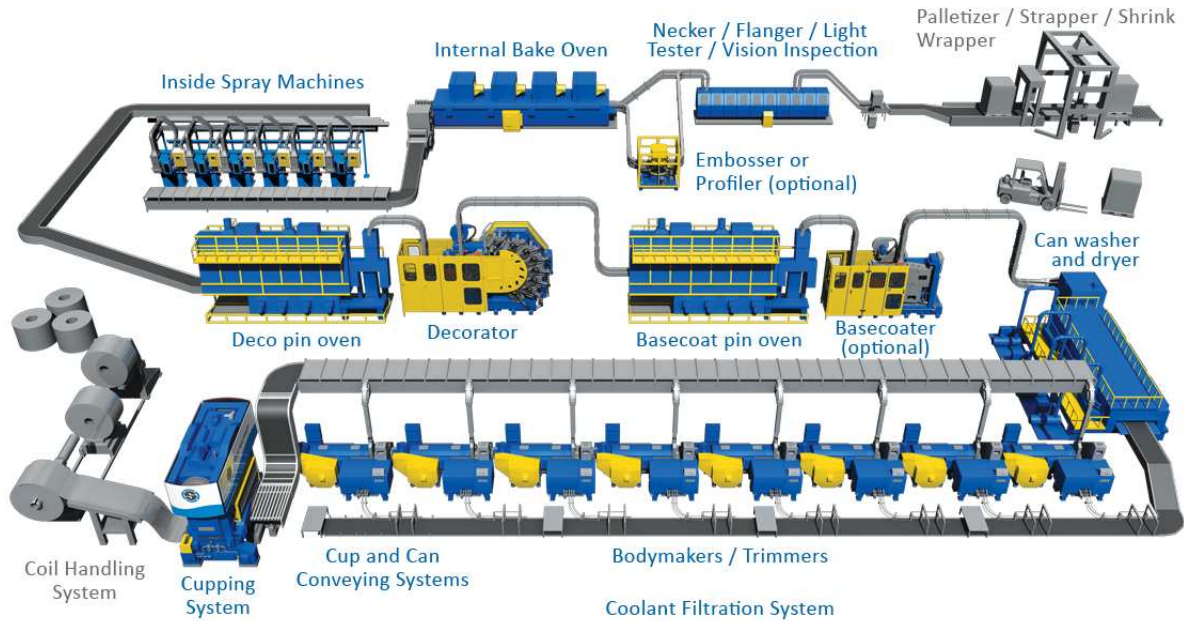


FIGURE 2. Can production equipment [11]

4. Practical Application. In this section, the main topics of the practical application developed will be discussed. Figure 3 shows the block diagram of the entire project.

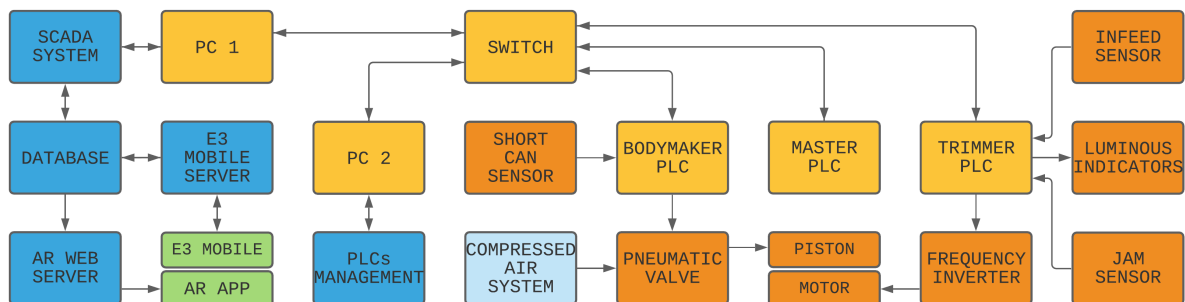


FIGURE 3. Diagram of relation between systems

4.1. Tools and methods. To achieve the objective of this work, the resources for software and firmware development used were: TIA Portal V15 (programming of Siemens PLCs and network commissioning), Elipse E3 Studio (development of the SCADA system), Microsoft SQL Server Management Studio 18 (database administration) and Unity 2019 (AR application development).

4.2. Commissioning of the PROFINET network. When configuring the PROFINET network, the TIA Portal tool is used, where individual addresses are assigned to the devices. The addresses are made up of the name, IP address and subnet mask. Table 1 shows the addresses of the devices used.

TABLE 1. Addresses table

Process nomenclature	IP address	Subnet mask
PLC Master	192.168.0.1	255.255.255.0
Switch	192.168.0.2	255.255.255.0
PLC Trimmer	192.168.0.3	255.255.255.0
PLC Bodymaker	192.168.0.4	255.255.255.0

The topology applied in the project is the star, with the switch as its central element. Figure 4 shows the system network topology.

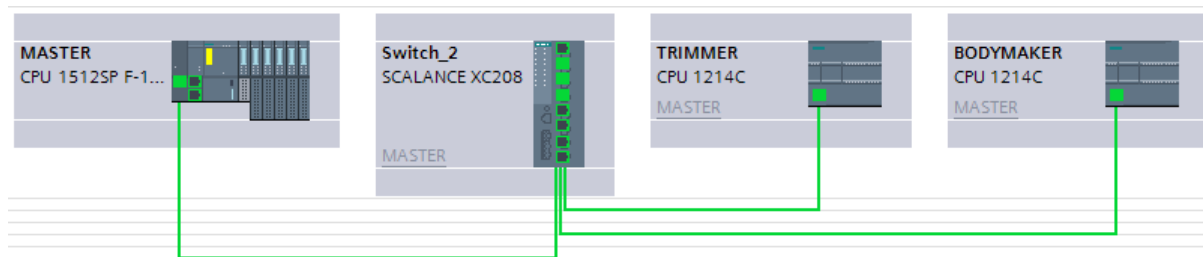


FIGURE 4. Representation of the network topology used in the system

The PLC Master is defined as an IO Controller and the PLCs Bodymaker and Trimmer, as IO Devices. To exchange data and communicate with IO Devices, the IO Controller must be used as a bridge for sending and receiving data and configure the IO Devices transfer areas, as shown in Figure 5.

I-device communication						I-device communication							
Transfer areas						Transfer areas							
...	Transfer area	Type	Address in IO contr...	↔	Address in I-device	Length	...	Transfer area	Type	Address in IO contr...	↔	Address in I-device	Length
1	MASTER_TO_BM	CD	Q 13	→	I 13	1 Byte	1	MASTER_TO_TRIMMER	CD	Q 12	→	I 2	1 Byte
2	BM_TO_MASTER	CD	I 21	←	Q 3	1 Byte	2	TRIMMER_TO_MASTER	CD	I 20	←	Q 2	1 Byte
3	BM_Q_TO_MASTER	CD	I 4...7	←	Q 6...9	4 Byte	3	-Add new->					
4	-Add new->												

FIGURE 5. Communication configuration between PLCs

To communicate a digital variable between the IO devices, the lines of the transfer areas BM_TO_MASTER and MASTER_TO_TRIMMER were used. Based on the assigned addresses, the logic is for Bodymaker to set a bit from Q3 memory position so that the Master recognizes this excitation in I21 memory position of the same bit. Therefore, the Master must set a bit from Q12 memory position so that the Trimmer recognizes this excitation in I2 memory position of the same bit. Thus, Trimmer identifies the state of the variable triggered by Bodymaker. Figure 6 shows this communication.

To communicate an analog variable, it follows the same concept applied to the digital variable, but it is necessary to change the size of the transfer area. It must occupy 4 memory positions, therefore using 4 bytes of space.

4.3. Communication between Master and Supervisory. The communication between the controller and Elipse E3 is done using the Siemens Multiprotocol (M-Prot) driver, using the Siemens ISOTCP protocol directly on the Ethernet port. On the M-Prot tab, the network type and rack number were modified, on the Setup tab, the physical



FIGURE 6. Simple program for communication between PLCs

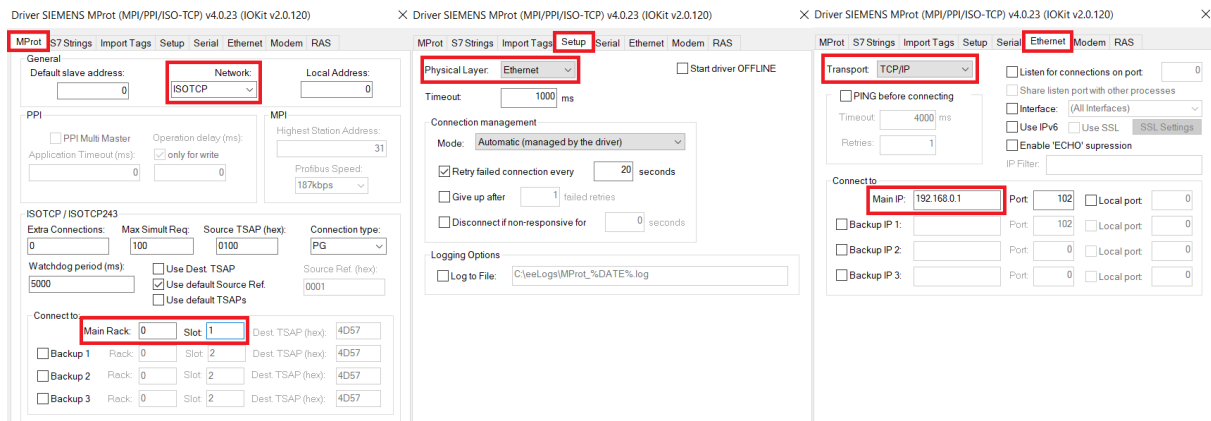


FIGURE 7. Configuration of the M-Prot driver for communication

Nome	Disp...	Item	P1/N...	P2/N...	P3/N...	P4/N...
Driver			0	0	0	0
Cans			1	708	0	2
BM_Information			1	106	0	21
TM_MS_State			1	106	0	20
System			1	107	0	1
Error_Tower			1	108	0	0
Control_Master			1	106	0	2
Control_Devices			1	106	0	1
Error_ShortCan			1	108	0	0
Error_Jam			1	107	0	13
MS_Mobile_Control			1	108	0	0

FIGURE 8. Configuration of driver tags

layer and, on the Ethernet tab, the protocol type and physical address of the controller, as shown in Figure 7.

It is necessary to create the communication tags and configure their P1, P2, P3 and P4 fields according to the protocol used, data types and data area, DB block number and address in the data area, respectively. Figure 8 shows these settings.

4.4. Mobile application. The Eclipse Mobile application is divided into Server (application server) and Client (visualization), allowing the creation of multiple applications

within the same installation, but one execution at a time [12]. In the developed application, a display and a graphic were inserted for the presentation of the production of cans and a setpoint to control the Master. The association of values is given by setting the tag property with the connection resources of Elipse E3. To perform remote access, the IPv4 address of the host where the mobile server is installed is used.

4.5. Augmented reality application. The elaboration of the remote access system with AR support was developed on the Unity platform, using the Vuforia package. The basic principle of operation of the application is defined by the diagram in Figure 9, whereas the identification of the target image is the first stage for the image display. Afterwards, the application periodically sends requests to a web server in order to retrieve the production and speed information from the database.

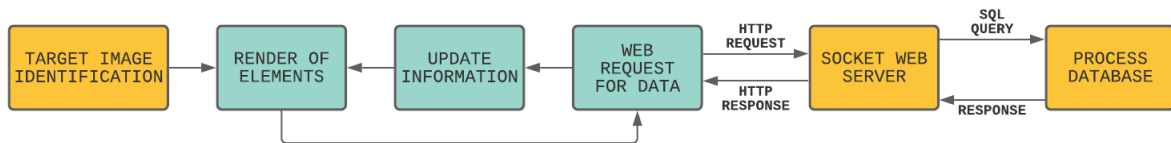


FIGURE 9. Operation diagram of the AR application

The Vuforia package version 8.5.9 provides tools for the identification of images, surfaces and rendering objects that overlap the real world, available in Package Manager within the Unity project. It is recommended to register on the Vuforia development portal, where a license will be generated, which must be inserted in the App License Key field. In the portal, it is necessary to set up a database where the images that will be recognized will be stored, becoming available for use within Unity.

In the developed application, the method of identifying images through QR Codes was chosen. To use this feature, simply add the Component Image Target Behavior to a GameObject and select the Database and Image Target. The display of objects starts after the identification of the images, these being the child objects of the GameObject with the Component Image Target Behavior. Figure 10 shows the structure for displaying the objects.

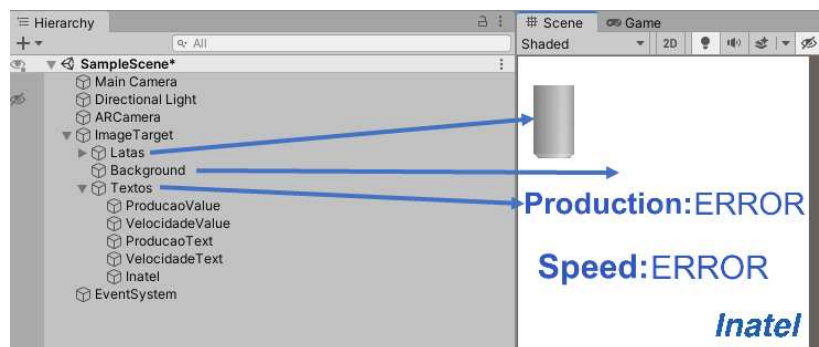


FIGURE 10. Arrangement of elements for display

The recovery of information for production and speed is done periodically every 5 seconds, while the image is being identified by the camera. At the end of the waiting time, a request is sent to a Socket Server on port 80 of the server, which retrieves the information from the Database and returns it in response to the application. Upon receiving the response, the displayed texts are updated. If the connection is not established, the text remains as “ERROR”, meaning that something did not go as expected.

5. **Results.** The final assembly of the communication obtained by the interaction of all equipment can be seen in Figure 11.

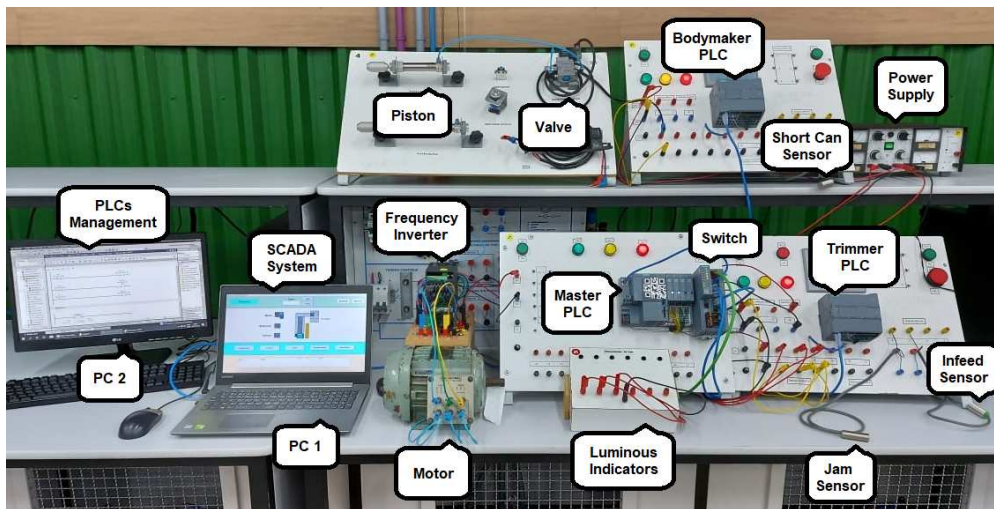


FIGURE 11. Final assembly of the proposed system

In Figure 12, Elipse Mobile works as a Server and as a Client. The Master is off and the momentary production is 1011 cans.

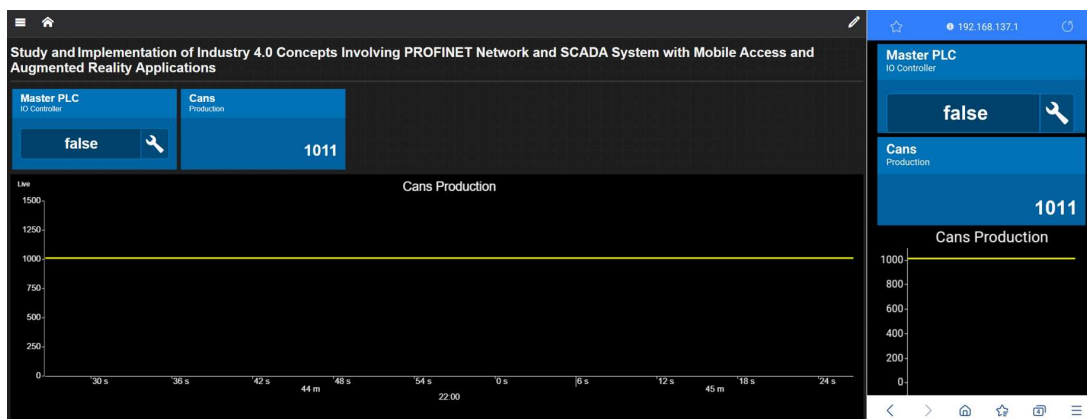


FIGURE 12. Server and Client screens developed on Elipse Mobile

The result of the application with augmented reality support that presents the user’s perspective through the application, can be seen in Figure 13. At this point in the process, the system has 644 cans with a manufacturing speed of 60 cans per minute (CPM).



FIGURE 13. AR application

In the supervisory system, four operation screens were created and they all contain a login area, date and time display, navigation buttons and field for monitoring alarms. Figure 14 shows the Overview and Control screens. On the Overview screen it is possible to view the current production, the operating speed and the states of the Master, Bodymaker and Trimmer through the colors green, yellow and red, corresponding to on, fault and off, respectively. On the Control screen, it is possible to operate the system by executing permissions to turn on, off and restart the machinery and view the operation of the sensors through errors that may occur in production.

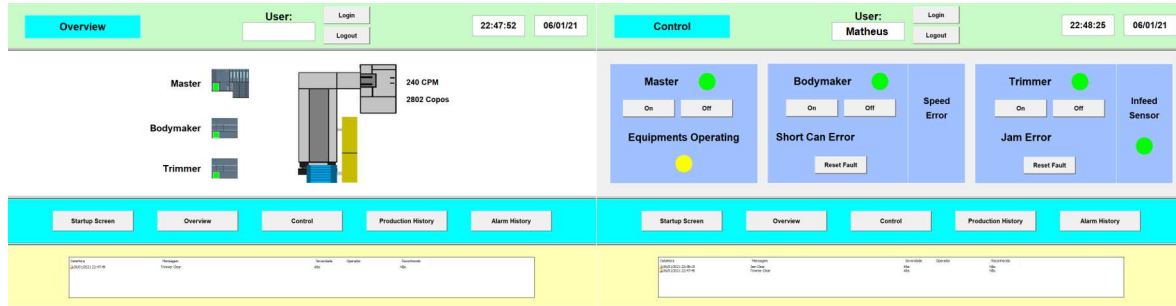


FIGURE 14. Overview and Control screens

Figure 15 shows the Production and Alarm Histories screens. On the Production History screen, it is possible to view the number of cans that have already been produced using a graph. In the Alarm History screen, it is possible to view, through a list, all alarms that have already occurred in the process containing the exact day and time.

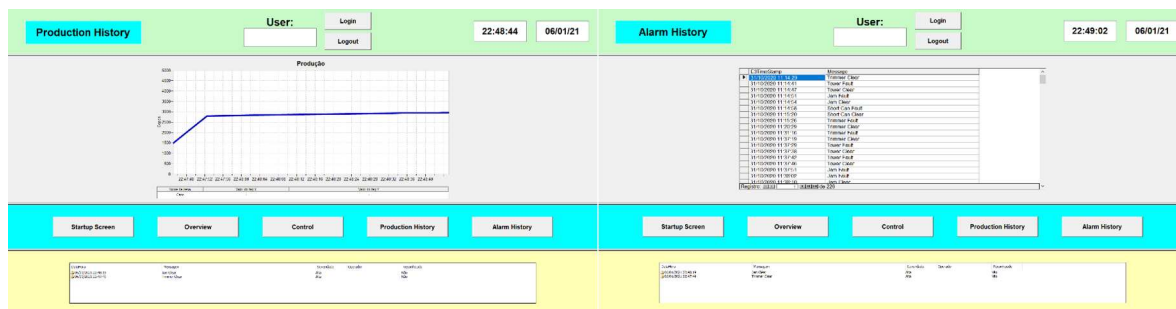


FIGURE 15. Production and Alarm Histories screens

6. Conclusion. This project demonstrates the practical development of a part of the real aluminum can manufacturing process with resources from Industry 4.0, revolutionizing manufacturing processes.

The technologies and communications systems used in this project have been successful in operation. The devices established communication, providing data exchange between the three programmable logic controllers with the SCADA system. The applications of Elipse Mobile and the application with interactivity of augmented reality, allowed the monitoring, analysis and remote intervention on the system.

It was found that with the change in the operating speed of the machinery, the pneumatic piston and the motor varied their speeds correctly. The sensors and light indicators operated exactly and precisely, contributing to the identification of possible failures and/or errors and in the states of the machinery and process, respectively.

A possible improvement for the project would be to explore Elipse Mobile's capacity more deeply. Another analysis to be carried out in future work is the temporal study of the communication latency of remote applications with the controller, in order to further complement this work.

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