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Environment for Education on Industry 4.0

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ABSTRACT A new industrial production model based on digitalization, system interconnection, virtualization and data exploitation, has emerged. Upgrade of production processes towards this Industry 4.0 model is one of the critical challenges for the industrial sector and, consequently, the training of students and professionals has to address these new demands. To carry out this task, it is essential to develop educational tools that allow students to interact with real equipment that implements, in an integrated way, new enabling technologies, such as connectivity with standard protocols, storage and data processing in the cloud, machine learning, digital twins and industrial cybersecurity measures. For that reason, in this work, we present an educational environment on Industry 4.0 that incorporates these technologies reproducing realistic industrial conditions. This environment includes cutting-edge industrial control system technologies, such as an industrial firewall and a virtual private network (VPN) to strengthen cybersecurity, an Industrial Internet of Things (IIoT) gateway to transfer process information to the cloud, where it can be stored and analyzed, and a digital twin that virtually reproduces the system. A set of hands-on tasks for an introductory automation course have been proposed, so that students acquire a practical understanding of the enabling technologies of Industry 4.0 and of its function in a real automation. This course has been taught in a master's degree and students have assessed its usefulness by means of an anonymous survey. The results of the educational experience have been useful both from the students' and faculty's viewpoint.

INDEX TERMS Engineering education, industry 4.0, industrial Internet of Things, IIoT, cyber-physical system.

I. INTRODUCTION

A new digitalization trend has emerged in recent years in the industrial sector, which commonly receives the name of Industry 4.0. This concept was coined by the German government in 2011 as Industrie 4.0, and merges information and communication technologies with the latest developments in the field of industrial automation [1]. This new paradigm, which some experts considered to be framed in the fourth industrial revolution, aims to the intelligent interconnection between machines and industry processes, merging virtual and real world [2].

The implementation of this new approach implies major changes towards a smart factory, achieved by a digital transformation of the industry [3]–[5]. This process involves a set of enabling technologies that link the physical world to virtual resources in order to accomplish an intelligent management of the industrial processes, obtaining an improvement in terms of productivity and management [6]. The digital interconnection leads to the concept of cyber-physical systems (CPS), which integrate computational and communication capabilities with physical processes [7], [8]. Network connectivity will allow devices to interact with each other by exchanging information acquired from the physical environment, making this information also accessible. This idea of interconnected environment is also at the core of the Internet of Things paradigm [9].

An information-centered scenario requires the use of different technologies such as cloud computing infrastructures or artificial intelligence capabilities in order to perform an adequate processing [10] of the large amount of data generated. Data analysis, as well as modeling tools, process simulation or virtual reality can also be used jointly for developing sophisticated models in digital twins that mirror all functional features of the system and help to predict future behaviors. Furthermore, cybersecurity should be taken into account to

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protect and ensure a correct functionality of all elements of the plant.

These emerging technologies are expected to have a significant effect in the industry for the coming years, giving companies a competitive edge. As a result, they develop a digital transformation that will involve extensive technical modifications in factories and, consequently, the presence of technicians with a deep knowledge of these technologies [11]. For that purpose, educational centers should anticipate the changes that occur in technologies in the field of industrial automation to train future qualified professionals properly [12]. Although there have been efforts to adapt education to Industry 4.0 requirements [13], [14], it is still a challenge to introduce new technologies in the classroom because available resources are often obsolete or can only be used in an isolated way, being difficult that students can learn how technology fully interacts in the whole system.

For these reasons, it is appropriate to use a facility that integrates these techniques so that students can profit from active interaction with them. In this paper, we propose the development of an Industry 4.0 demonstration model oriented to narrow the gap between theoretical teaching and its practical implementation in the industry. The contribution of this work is a realistic industrial environment, simple enough to be managed easily by students, that integrates multiple enabling technologies of Industry 4.0. The environment is used for performing several hands-on tasks in a Master's degree course and it is assessed using a survey from the opinions of the students.

The paper is structured as follows: educational needs in the context of Industry 4.0 and previous experiences are presented in Section II. In Section III, the methodology proposed for the development of the demonstration model is explained in detail. Section IV describes the educational tasks that were designed and applied to a Master's degree course. The results of the educational experience, which was assessed by students through questionnaires, are presented in Section V and discussed in Section VI. Finally, conclusions are drawn in Section VII.

II. BACKGROUND

A. EDUCATION FOR INDUSTRY 4.0

Since the scope of the Industry 4.0 initiative is extensive [15], [16], its transformation is not only constrained to industry but it also involves impacts in economy, society and education. Universities play an essential role in the acquisition of the new required abilities [11], which are defined as a combination of multidisciplinary skills [13], [17]. For that, it is necessary an adaptation of current programs, curricula, and also the development of realistic environments that facilitate the use of the technologies introduced in industry [14], [18].

In this context, the concept of Learning Factory (LF) [19] appears, i.e., a demonstration model of what a factory would be, designed only for training of future employees [20]. The development of initiatives of this type allows to build skills and knowledge in industrial engineering, in a more advanced way than with strictly theoretical approaches [21]. A main advantage of this approach is its integrated nature, which lets students understand relationships between concepts and technologies in an industrial environment. There are several developments related to learning factories for training in production and manufacturing lines [22], industrial applications of a more general nature [23], or specific technologies in greater depth, such as cybersecurity [24] or virtual and mixed reality [25].

However, a realistic educational environment for Industry 4.0 needs to cover a wide range of its enabling technologies, such as connectivity with standard protocols, storage and data processing in the cloud, digital twins and industrial cybersecurity measures. A wide coverage of technologies is also necessary to ensure flexibility, i.e., the ability to be used in different learning scenarios. Along with the development of learning factories, there are more examples that respond this demand. Virtual and remote laboratories have been proposed to allow students to learn without physical access to the place where the plants or industrial models are located [26], [27].

The purpose of engaging students in the acquisition of hands-on knowledge leads to an interactive teaching approach, which has showed academic and practical benefits [28]. In this sense, the Industry 4.0 Technologies Laboratory (I4Tech Lab) [29] provides an active learning environment for academic, research and industrial promotion of novel technologies. As well as in the work proposed in this paper, the I4Tech Lab addresses education for Industry 4.0 through the development of a realistic environment with multiple technologies available. In that case, the laboratory deploys enabling technologies such as IIoT or augmented reality in an industrial manufacturing environment. A five-stage academic method is proposed to adapt teaching to the new requirements.

Another practical framework is proposed in [30] which is not only a modern automation laboratory but also a remote access initiative to integrate distance learning. Furthermore, the work presented in [31] is focused specifically on the implementation of digital twin technology in engineering education, which is an important concept in the field of Industry 4.0.

B. TECHNOLOGIES

As discussed in section II-A, a demonstration model on Industry 4.0 must include essential characteristics of a real industrial process, reproducing realistic industrial conditions, as well as new enabling technologies (see Figure 1). As a result, several aspects must be considered, ranging from automation to IT-related services. With regard to automation, there are some representative approaches common to most Industry 4.0 implementations. For instance, centralized control of a production process is no longer usual, giving way to distributed and decentralized architectures where control systems communicate with each other through standard industrial communication protocols [32], [33].

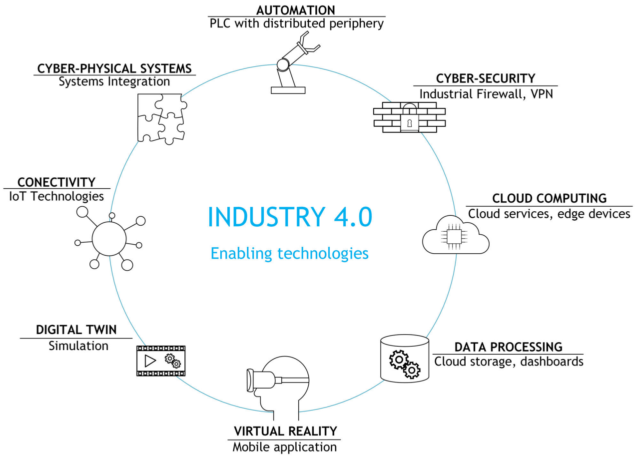
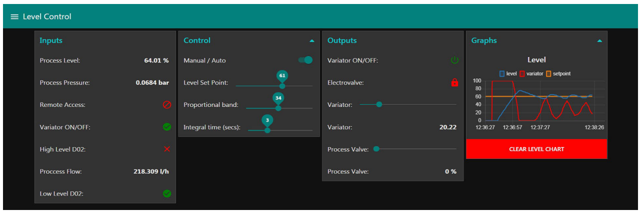


FIGURE 1. Enabling technologies needed for a demonstration model on industry 4.0.

To achieve the convergence between information technologies (IT) and operation technologies (OT), it is necessary an efficient exchange of information through the integration of systems, which supports decision making to increase productivity, decrease losses, and optimize resources. There are different alternatives to carry out the above-mentioned system integration [34], [35], which can rely on technologies such as Node-RED, an open-source visualization tool created by the IBM Emerging Technology team that allows to interconnect all the elements of the Internet of Things.

Node-RED not only can work with cutting-edge equipment of large manufacturers, but also with resource-limited devices [36]. Being based on Node.js, it allows simpler creation of APIs by implementing nodes through a palette (library). Thanks to these nodes, it is possible to easily communicate devices using standard industrial protocols present in different fields of automation [37], [38]. With Node-RED, it is possible to develop dashboards for monitoring and control that are useful in an education context (see Figure 2). Other alternative open-source frameworks are NETLab Toolkit, which supports different languages for the integration of IoT devices and it is specialized in algorithms of artificial intelligence, or Eclipse IoT, which facilitates the creation of applications for constrained devices, gateways and cloud back-ends [39].


Level Control

Inputs
Process Level: 64.01 %
Process Pressure: 0.0684 bar
Remote Access: ⊘
Variator ON/OFF: ✓
High Level D02: ✗
Proccess Flow: 218.309 l/h
Low Level D02: ✓

Control
Manual / Auto ●
Level Set Point: 61
Proportional band: 34
Integral time (secs): 3

Outputs
Variator ON/OFF:
Electrovalve:
Variator:
Variator: 20.22
Process Valve:
Process Valve: 0 %

FIGURE 2. Example of a Node-RED dashboard: User interface for the remote control and monitoring of level, hosted in the cloud.

In terms of the connectivity, standard communication protocols such as Message Queuing Telemetry Transport (MQTT) [40] or Constrained Application Protocol (CoAP) [41] play a fundamental role. Created for machine-to-machine (M2M) communication, they facilitate the integration due to its lightweight nature and its security features, providing real time communication with cloud services while ensuring certain level of confidentiality and integrity, required in public networks. Another alternative communication protocol would be OPC UA, which is a modern industrial communication standard, based on the classic client/server architecture [39], [42]. This protocol allows both horizontal M2M communication and vertical communication with cloud services. OPC UA also includes security measures, such as message signing and encryption or certificates. Finally, there is a growing use of more general technologies such as HTTPS and Restful web services in industrial applications [43].

These communication technologies contrast with specific industrial protocols that are traditionally used for the operation or configuration of control systems, such as PROFINET, Modbus TCP or S7, which lack encryption, integrity checks or authentication. However, cybersecurity is essential in the context of Industry 4.0, so security measures such as segmentation, filtering and monitoring are especially relevant in the networks where these protocols are found. A usual approach to improve cybersecurity is that of defense in depth, which consists in layering different security mechanisms to reduce the chance of a successful attack [44]. These security measures can be applied to data, applications, hosts, networks, physical and logical perimeter, and policies.

The use of network segmentation and filtering is recommended and can help mitigating protocol deficiencies. To this end, firewalls, especially those ones adapted to work in industrial environments, should be used. An interesting property that these firewalls should include is deep packet inspection, i.e., application-level filtering for industrial-oriented protocols [45]. Perimeter protection is also of extreme importance and virtual private network (VPN) connections with appropriate encryption and security [46] should always be used for remote access to the internal network.

A digital twin, which is a realistic virtual copy of the system obtained through modeling tools, is presented as another key aspect in this paradigm [47]. The concept of digital twin allows the convergence between physical and virtual processes and the corresponding data linked to them [48]. These technologies allow building a mirrored version of the real system, where parameters can be modified to predict system behavior, obtaining useful knowledge to optimize the manufacturing process and prevent errors [49]. In demonstration models on Industry 4.0, virtual reality technology is other feature, that has been developed over time and has become a popular topic for educational research in the last decade [50]. This technology has the ability to improve the student's perception skills as well as enhance their abilities [51].

On the other hand, it is becoming increasingly common for industry to host data or allocate services in the cloud for various purposes, because of the advantages it provides with regard to costs, flexibility, continuous support or security.

We can distinguish three approaches to cloud computing in this field: Infrastructure as a Service (IaaS), Software as a Service (SaaS) and Platform as a Service (PaaS) [52]. In IaaS, a supplier provides customers with pay-per-use access to storage, networks, servers and other computing resources in the cloud. SaaS provides applications over the Internet under users' subscription. Finally, PaaS means that the service provider offers access to a cloud-based environment in which users can create and distribute applications.

AWS (Amazon Web Services), Google Cloud Platform, Microsoft Azure, or IBM Cloud are some of the most prominent commercial cloud providers and widely known for the variety of services they incorporate. Among the products offered by the different cloud platforms, it is worth highlighting those ones that provide storage and virtualization servers, apps deployment, virtual and physical network management, security and monitoring tools, database administration, environments for the integration of systems and, finally, data analysis techniques. These data analysis services are essential for any cloud-based platforms because they allow real-time and decentralized decision making, while facilitating the implementation of artificial intelligence techniques.

III. PROPOSED APPROACH

As previously discussed throughout the document, the main aim of this work is to propose a realistic environment for education in Industry 4.0, which is flexible and simple enough to be managed in different learning scenarios. For that purpose, the learning environment is designed as a replica of a real one, using a learning factory approach to provide the students an educational viewpoint of the industrial reality.

The proposed approach is oriented to provide introductory training in a wide set of well-integrated enabling technologies, focusing on a clear understanding of their function in the system instead of a deeper knowledge of its implementation or specific details. Although this educational perspective contributes to emphasize key concepts over technical details, it is still a challenge that the addition of enabling technologies does not increase complexity. For this reason, the educational approach should be focused on solving hands-on tasks linked to the operation of different enabling technologies, without losing the perspective of the whole system.

For that purpose, the proposed environment includes the necessary elements for the control and monitoring of an industrial process, using technologies that are representative of the current state of the art. The system architecture, which is shown in Figure 3, is designed to emphasize characteristic technologies of the digitalized industry, such as cloud computing, digital twin or cyber-security measures. The implementation of this architecture is described in detail in the following subsection.

A. IMPLEMENTATION OF THE ENVIRONMENT

The proposed environment is based on an industrial pilot plant [53] with educational purposes but industrial instrumentation that includes three separate circuits. The main process circuit is designed for controlling four variables (level, flow rate, temperature and pressure) of a circulating fluid. It contains two tanks or reservoirs interconnected at different heights, a centrifugal pump, different valves to move the fluid or regulate the flow rate, and several sensors to allow the implementation of control loops for the aforementioned variables. The other two circuits are related to temperature: a heating circuit consists of a tank to store hot water, heated using electrical resistors, and transfers heat to the process through a plate heat exchanger; and, finally, a cooling circuit recirculates the coolant from an external supply using another plate heat exchanger. The physical system can be seen in the annotated Figure 4.

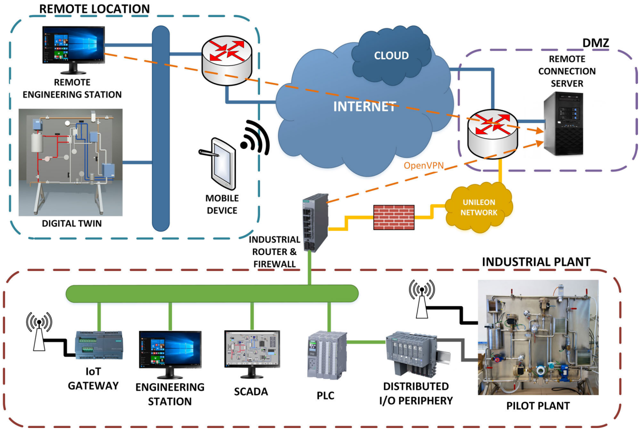


FIGURE 3. Network architectur.

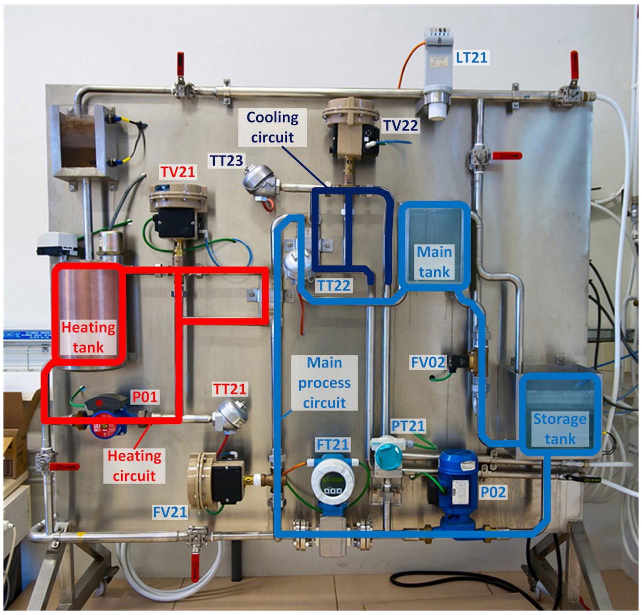
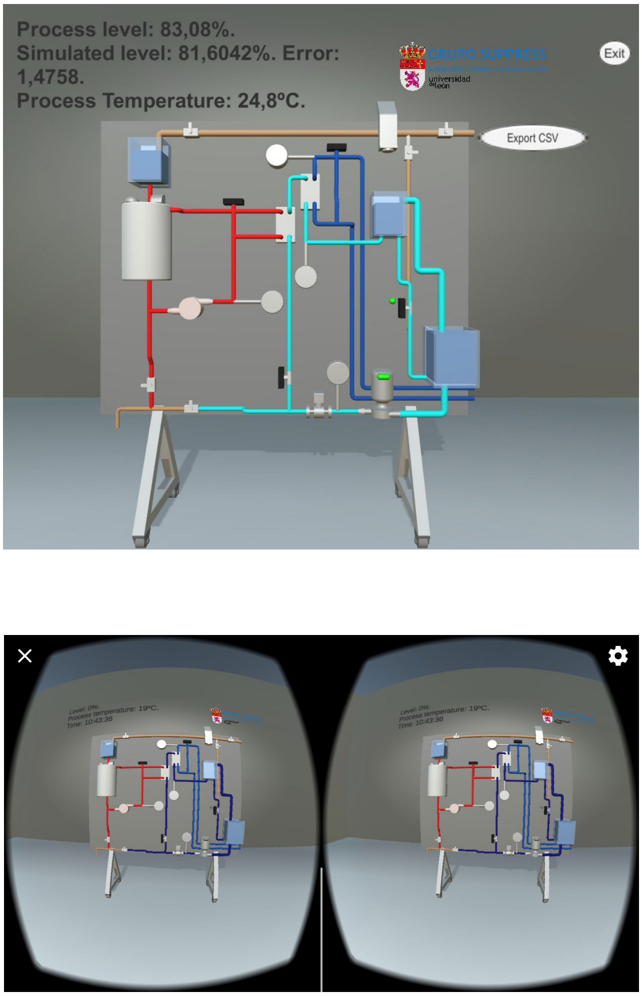


FIGURE 4. Physical system.

This process is controlled by a programmable logic controller (PLC), manufactured by Siemens, which provides PROFINET communication [54] and uses a distributed I/O for signal acquisition. These elements are configured from an



Process level: 83,08%.
Simulated level: 81,6042%. Error: 1,4758.
Process Temperature: 24,8ºC.

FIGURE 5. Desktop version (top) and virtual reality glasses version (bottom) of the digital twin.

engineering station. The process is monitored with a SCADA system in another workstation. The industrial plant and the distributed I/O are installed in one laboratory, whereas the rest of the equipment is located in another one, so PROFINET communication between these laboratories is made through a private network, isolated from the rest of the university network.

The network architecture is segmented using four different zones, as it is shown in Figure 3. The industrial zone includes all the previously mentioned elements of the plant plus an IoT gateway, which is an edge device in charge of communication with cloud services. Communications in and out of this zone are filtered by an industrial router/firewall. This device enforces the isolation of the zone but it is also an endpoint of the VPN connection that allows secure remote access, administration and configuration. This access is provided by a Remote Connect server in a demilitarized zone (DMZ) that exposes the external-facing service of the environment. Different clients can connect to the system externally through VPN, including a remote engineering station and the digital twin. Finally, the cloud platform uses the services provided by IBM Cloud [55] and its IoT Platform [56] for data storage, analysis and visualization.

The digital twin included in the environment provides the physics-based modeling of the industrial pilot plant, its virtual reality representation and data acquisition from the cloud platform. For the simulation, the equations that describe the behavior of the process circuit have been used. The aim is to provide students with an understanding of the key features of the physical behavior rather than a high fidelity and multi-scale simulation of the physical entity. The virtual representation uses a three-dimensional model of the pilot plant. Visual features such as the color of circuit pipes to represent the temperature of the fluid or numeric values are added to support this representation.

The digital twin has been developed using the Unity 3D software, that, although designed for videogame development, provides a suitable framework for the implementation of virtual reality (VR) simulations that can be run in a mobile device. It must be noted that an alternative would be the use of specific applications currently provided by industrial manufacturers. These tools would be more suitable to develop high-fidelity simulations that are closely integrated with the automation technologies. The 3D engine provides the functionality necessary to allow an easy graphical representation of the dynamic behavior, which is simulated by scripts programmed using C#. The digital twin has been developed for Windows and Android, including a virtual reality version for the latter that can be used immersively with VR glasses, although it could be easily ported to other platforms such as Linux or iOS. Figure 5 shows the 3D representation of the digital twin in its desktop and mobile VR versions.

In the developed environment, different communication flows are generated, as shown in the activity diagram in Figure 6. First, in the control loop, the PLC cyclically reads analog and digital inputs from the distributed I/O, computes the control actions and write them to the outputs, again through the distributed I/O. If necessary, configuration and management tasks on the control device can be performed either locally, from the engineering station in the industrial plant, or from a remote engineering station by means of the VPN connection. Parameters, setpoints and/or manual values can also be modified whenever the operation requires it, either from the SCADA or from the Node-RED dashboard in the IoT gateway.

The system monitoring is also performed through the SCADA or through the Node-RED dashboard in the IoT gateway. Both platforms communicate with the PLC through the PROFINET protocol. In the IoT gateway, the variables are also transferred to the cloud using the MQTT protocol, which is suitable for communication in public networks. In the cloud, data are stored in the corresponding database, processed and visualized. The digital twin obtains from the cloud the inputs needed for the simulation.

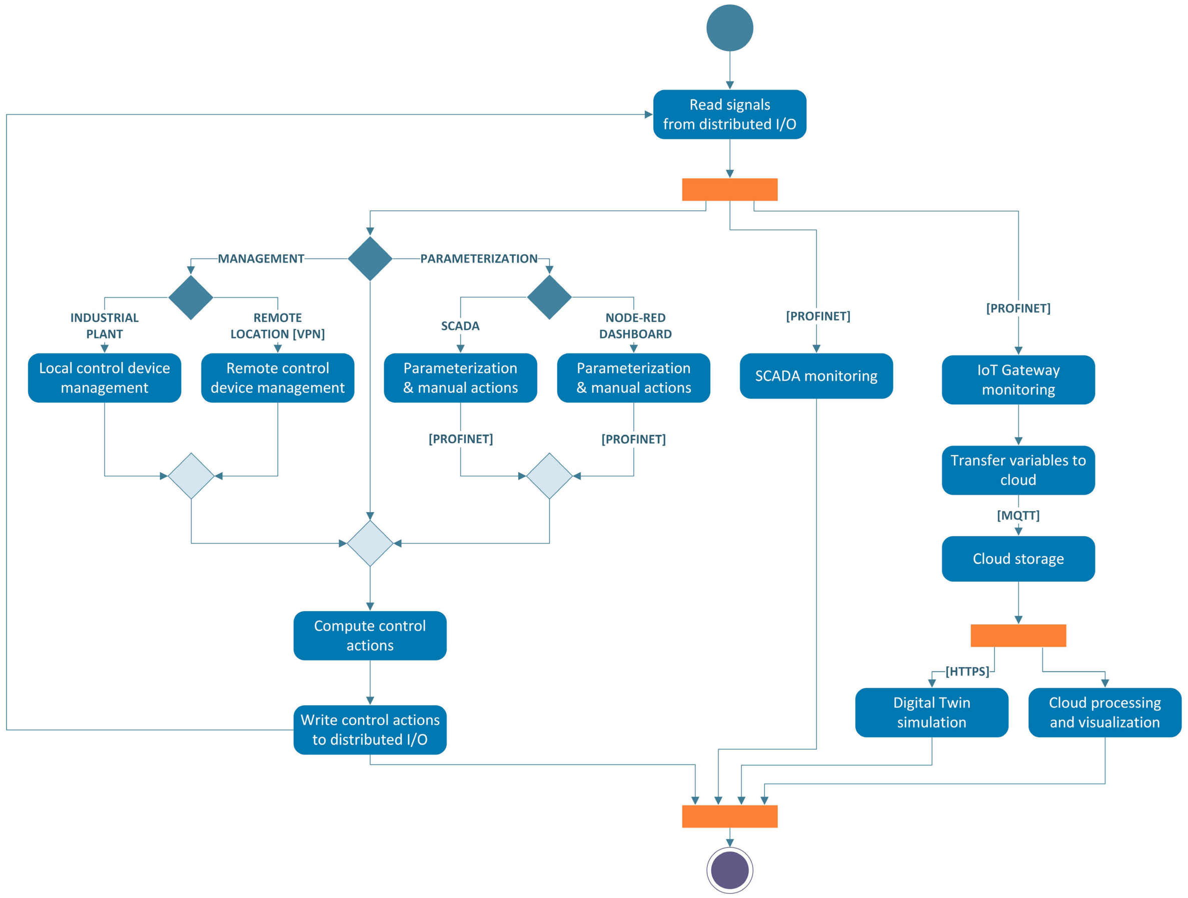


FIGURE 6. **Activity diagram.**

IV. EDUCATIONAL EXPERIENCE

The demonstration model described in section III has been used for the 2020 academic year in the course on Automation and Process Control of the Master's Degree in Production in Pharmaceutical Industries, a recently introduced degree with 20 students that have background in engineering and/or biotechnology. This course aims to introduce students in the field of automatic control. It has been selected for evaluation of the proposed approach due to the profile of the students and the degree. The students lack a background on specific automation technologies, and it is therefore possible to assess the acquisition of introductory concepts. On the other hand, the master's degree has a clear industrial orientation and was designed to meet a knowledge gap in the regional biopharmaceutical sector. It is thus expected that these students are representative enough for the proposed aims.

The proposed activities aim at letting the students understand the operation and functionality of enabling technologies of Industry 4.0 that are described in section II. The proposed hands-on tasks, aligned with the enabling technologies, are designed to be done in groups of 3 students, although some sections, such as simulations, are individual (see task four below). A guide to carry out the tasks is available in the institutional learning management system,which starts by highlighting the characteristics of enabling technologies that were previously explained in the theoretical sessions Next, the actual implementation of this technology in the educational environment is broadly described. Finally, the proposed activities are explained. They can also ask questions in a forum/chat available on the learning management system. In lab sessions, which are two hours long, the teacher is in the classroom to provide guidance and technical support. The understanding of the activities performed in this task and their link with theoretical concepts are later assessed in the final exam of the course.

In the first task, ''Automation'', the configuration of the programmable controller and its distributed I/O is accomplished. Therefore, the aim of this task is to present the process that serves as the basis of the educational environment. Specifically, students need to review the hardware configuration of the PLC, that includes analog/digital inputs and outputs connected using the distributed I/O, and to develop control strategies. Configuration of these devices is performed through the engineering workstation. Furthermore, the students validate their works by carrying out local monitoring through different screens of the SCADA system. Initially, the whole process is visualized and then it is possible to work with each one of the circuits separately. In the SCADA,

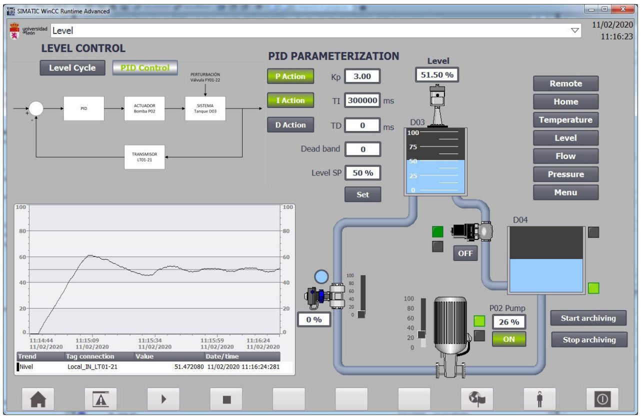


FIGURE 7. Local SCADA used by students in the first task.

students configure trend charts of main variables from the industrial plant (level, flow rate, temperature and pressure). Figure 7 shows a screen of the local SCADA system corresponding to the level control for the main tank, used by students during the first task.

The second task, "Remote monitoring", is focused on connectivity and systems integration and it is expected that the students understand the environment as a cyber-physical system, where certain specific communication protocols are used. For that purpose, students perform remote monitoring of the process through a dashboard of the IoT gateway. To access the gateway interface, it is not necessary to install any additional tool but only a web browser with access to the environment's network. A student can browse through the different dashboard screens, such as those ones designed to monitor, and observe the status of the processes that are taking place. In addition, if the remote mode is activated, the user can interact with the process, submitting control actions and visualizing the results produced in the real system by means of charts. Using the Node-RED environment as a connectivity tool, it is possible to access the information offered by different devices through different communication protocols.

The third task, "Cloud computing" is oriented to let students discover data storage and processing in the cloud. The data read through the IoT gateway are stored in the database using the IBM Cloudant service . With the use of this service, students are able to visualize the history of data sent from the industrial plant, to carry out queries combining different variables and also to export data sets, according to diverse criteria. In this task, students also explore other services available on the cloud platform, such as the one that facilitates the execution of a virtual machine hosted in the cloud, where another Node-RED environment is installed for control and monitoring.

In the fourth task, "Digital twin", the students use the digital twin of the industrial plant. This task is oriented to let the student understand the uses of simulation and the possibilities of virtual reality in industrial contexts. The three-dimensional representation linked to the process model allows the students to manage a virtual reality simulation of the process in any device, including mobile ones. The student can observe the system response to a specific control action, e.g, the tank level response to a certain pump setpoint. The data generated during the simulation can be downloaded as a file with csv (comma-separated values) format so that the student can compare simulated and real data and compute the error observed between them, as shown in the example in Figure 8. In addition to running the digital twin in a desktop environment, students also explore its virtual reality version with glasses that adapt their cell phones for a 3D real-time display.

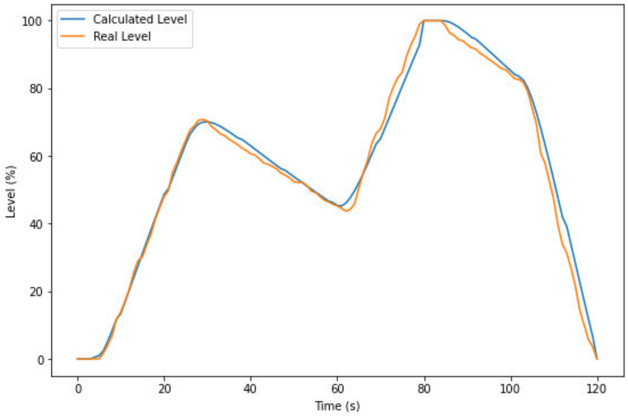


FIGURE 8. Example results of the fourth task (digital twin).

In the fifth task, "Cybersecurity" students are introduced to basic cybersecurity measures. They use the firewall to explore configuration possibilities and filter data packets coming from outside of the industrial network. By activating or deactivating the corresponding firewall rule, they check, for instance, how to prevent access to the IoT dashboard from any external computer. Other cybersecurity aspect considered in this task is remote management, where students perform remote maintenance of the industrial process through a secure VPN connection. The students run the remote connection client from devices external to the industrial plant network and access different devices connected to the industrial plant, such as the controller, the engineering station with the PLC programming software, the SCADA system or the IoT gateway dashboard.

V. RESULTS

The usefulness of the proposed approach for the acquisition of key concepts and knowledge about the function of technologies in Industry 4.0 is assessed through the perception of the students. For that reason, all the students enrolled in the Automation and Process Control course anonymously answered a questionnaire after carrying out the activity proposed in of the Master's Degree. This questionnaire, shown in the Table 1, uses the well-known System Usability Scale (SUS) [57], which consists of 10 questions aimed at

TABLE 1. **Questionnaire.**

Q1	I would like to use this system frequently
Q2	I found the system unnecessarily complex
Q3	The system was easy to use
Q4	I would need the support of a technical person to be able to use this system
Q5	I found the various functions in this system were well integrated
Q6	There is too much inconsistency in this system
Q7	I imagine that most people would learn to use this system very quickly
Q8	I found the system very cumbersome to use
Q9	I felt very confident using this system
Q10	I needed to learn many things before I could get going with this system
Q11	I consider this environment useful for consolidating theoretical knowledge
Q12	I improved my learning using the demonstration model of Industry 4.0
Q13	The demonstration model increased my motivation in the learning process
Q14	I would like to perform more hands-on tasks with this educational environment
Q15	This hands-on task has allowed me to acquire the knowledge relative to the enabling technologies of Industry 4.0

evaluating the usability of a given system. In addition, five supplementary questions have been added to better understand the student's perception of learning with the educational environment. In order to answer these questions, the student must select among 5 available options: completely agree (5), agree (4), neither agree nor disagree (3), disagree (2), completely disagree (1). Of the first 10 proposed questions, it should be noted that the odd ones are posed as positive statements and the even ones are negative statements. The results of the questionnaire are shown in Figure 9.

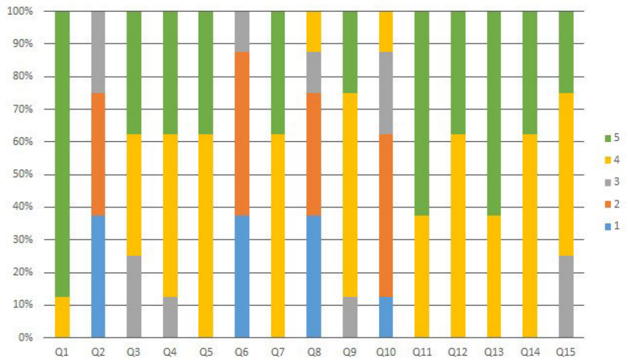


FIGURE 9. **Responses to the questionnaire.**

The aim of the SUS questionnaire is to provide an evaluation of the usability of the environment, by obtaining a number, from 0 to 100. The calculation of the score with the SUS system is obtained in the following method: initially, the answers to the first 10 questions are assigned in a range of 0 to 4 points. For this purpose, the score of the positive questions (1, 3, 5, 7, 9) is computed as the result minus 1, whereas for the negative questions (2, 4, 6, 8, 10) the result obtained is subtracted from 5. Finally, the scores obtained are added together and the result is multiplied by 2.5, to adjust it to a range between 0 and 100 points. The experience performed with the educational environment for Industry 4.0 achieved an average score of 74.6, with a maximum value of 87.5, a minimum of 62.5 and a median of 72.5. According to the scores obtained, we might consider that the educational environment is usable enough, having an average score higher than 70 over 100 points.

The 5 additional questions are not be considered for the usability score, but they provide a broader perspective of the students' perception about the environment of Industry 4.0. Observing the results obtained in these questions (see Figure 9), it can also be concluded that the use of the environment has been perceived as positive by the students.

VI. DISCUSSION

According to the results presented in the previous section, the proposed approach can be appropriate for consolidating theoretical knowledge, since it increases motivation in the learning process and helps to acquire the technical skills needed for the operation of the enabling technologies of Industry 4.0. All the students expressed their desires to perform more hands-on tasks with the environment and thought that the different functions were properly integrated. Students showed, in general, a good grasp of key concepts and of the link between specific technologies in the environment and its function in industrial digitalization.

The development and use of demonstration models, where students can perform hands-on tasks with an enabling technology that is not isolated but integrated in a larger realistic environment, is aligned with the approaches found in the literature, as described in Section II-A. However, most previous work focuses on an individual technology, allowing educational approaches where students can learn the concepts and practical aspects of that technology in greater depth. In contrast, the environment proposed in this paper covers a wide range of enabling technologies to be adapted for courses where students require an introductory but global view of Industry 4.0. This orientation can be seen as a strength rather than a limitation, because its adaptation for more specific learning scenarios would be only a matter of developing educational contents. Indeed, the proposed environment would be useful to train students with stronger background on automation or information technologies, since it is possible to define hands-on tasks oriented to configuration in detail rather than to the operation of the system. However, it must be noted that the educational approach should be adapted and that a procedure of reconfiguration between sessions should be defined.

A more related work is the Industry 4.0 Technologies Laboratory (I4Tech Lab) presented in [29]. This laboratory also includes several enabling technologies such as cloud computing, connectivity in the context of Industry 4.0 or augmented reality, as well as the proposal of a set of tasks for practical training. In comparison to I4Tech Lab, the proposed environment includes cybersecurity and digital twin as additional features. The assessment of the environment through questionnaires answered by students is also a differential contribution of our work. The environment proposed in this paper states simplicity as a key feature, unlike the I4Tech Lab that uses a complex industrial cell for flexible automation as its basis. From a technical point of view, simplicity is appropriate because the operation and maintenance of the system might lead to excessive workload for faculty. But from the point of view of student learning, the environment also needs to be easy to use, to complement the theoretical knowledge and increase student motivation.

In this sense, most of the students stated that the system has the appropriate complexity and is easy to use, although they felt the need of support by faculty and/or technical staff to solve specific problems or restart the system. However, a minority of students considered that the environment is cumbersome or thought that they needed to learn too many theoretical concepts before operating the system. This is understandable given the hybrid nature of the Master's Degree in Production in Pharmaceutical Industries, with students coming from both engineering and natural sciences backgrounds, as discussed in section IV. On the other hand, the use of the environment did not drastically increase the workload of faculty. Nevertheless, alleviating the workload needed to maintain the environment operative should be a target of future improvements of the implementation.

New improvements should also be oriented to complement existing technologies and provide alternatives. For instance, it would be interesting to include modular a SCADA platform with greater flexibility to provide data analysis and management functionalities. The use of industrial-oriented tools for the development of a digital twin would also allow enriching the educational task by letting the students analyze not only the resulting simulation but also its development process. Finally, a specific task on data analysis would establish a link between the course and further specialization in fields such as predictive maintenance or business intelligence.

VII. CONCLUSION

This paper proposes an approach for the development of a learning environment in the field of Industry 4.0. The environment is designed as a complete facility, following the concept of learning factory, where the new enabling technologies associated with this industrial paradigm are available. This way, students consolidate their theoretical learning through experimentation with real equipment, similar to what they will find in the professional context. The environment allows students to perform hands-on tasks linked to a wide range of technologies, but without losing the focus on the complete system integration. The proposed demonstrator model is easy to use but also easy to adapt and maintain.

A platform to set up the educational environment on Industry 4.0 was deployed, integrating industrial devices and software, communication and cybersecurity elements. The automation architecture of this demonstration model includes control devices that communicate with standard protocols. Cybersecurity is strengthened by firewalls ready to work in industrial environments and VPN services. To cover the concepts of digital twin and virtual reality, a 3D-enabled simulation that can be used with mobile devices and virtual reality glasses was developed. The environment also includes cloud storage and computing resources. The cloud link service uses the Node-Red tool, widely used for IoT integration, in an edge device. The MQTT protocol is used for communication with the cloud, because it is suited to communication of process data in public networks.

A set of hands-on tasks have been developed for an introductory course at a Master's degree level. Students have performed activities with the demonstration model for each one of the enabling technologies: automation, remote monitoring, cloud computing, digital twin, virtual reality and cybersecurity. Finally, a survey has been conducted to evaluate the environment. The results show a great acceptance of the initiative among the students, because it helped them to acquire new practical concepts and increase their motivation for learning. Furthermore, the environment was generally considered easy to use, although the students noted that several theoretical concepts were needed in advance and that support from faculty was necessary during the experience.

Future work should be focused on complementing the existing technologies in the environment while alleviating the workload necessary to maintain the demonstrator operative.

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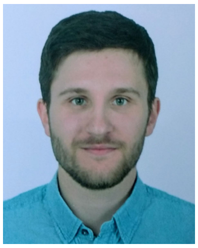

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