Industry 4.0 Laboratory: Cyber-physical Systems, Industrial Internet of Things and Artificial Intelligence

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***Abstract*— In recent decades, information and communication technologies have been successfully transferred to complex industrial processes. In the real world of industry, the vast majority of automated systems are based on these technologies for operation. Today, the latest advances in information technology are deepening into the production sector, where their use, such as artificial intelligence or cloud computing, is starting to become a reality. The use of these technologies will increase the efficiency and productivity of production processes, and will also allow for the manufacture of designs focused on the mass individualized production model effectively. The evolution of classical production systems towards cyber physical systems is a crucial step, enabling the implementation of intelligent control and monitoring technologies over current industry context, thus exploiting their full potential. This publication presents the work carried out in the development of a research and development laboratory focused on Industry 4.0, the I4TechLab. Some of the novelties that it entails are the implementation of an Industrial IoT (IIoT) architecture based on the concept of API as Administration Shell and the deployment of intelligent control applications based on artificial intelligence for the industrial process.**

Keywords— Industry 4.0, Industrial Cyber-physical Systems, Industrial Internet of Things, Administration Shell, Artificial intelligence, Industrial Automation

I. INTRODUCTION

In the new Industry 4.0 paradigm the industrial competitiveness is related with efficiency and sustainability. Future industrial sector must evolve towards autonomous and smarter factories with increased levels of interconnectivity along the product life cycle in order to make optimized decisions. In this regard, the deployment of intelligent support systems has become a desirable approach in which the industrial production is continuously assisted by digital applications providing upper optimization loops than those related with the machinery operative control. Indeed, in the forthcoming digitized factories, the focus is on automatic gathering, data processing and autonomous decision making over processes and production according to different criteria such as market demand, logistics, economics and quality among others. However, its effective implementation represents a challenge for most manufacturing small and medium enterprises (SMEs).

In order to reach a feasible implementation of smart manufacturing processes, manufacturers have to be ready to digitize manufacturing procedures through automated model architectures designed to do so. In this regard, the industrial sector has for many years been guided by the conventional CIM automation pyramid. However, new application demands for smart production processes and increased information exchanges, are leading to further (complementary) developments.

A major step in developing new information models in the industrial automation environment came with the recognition that it is not sufficient to provide integration within the automation levels. The traditional hierarchical automation pyramid is often seen as a physical structure of production systems. However, by introducing new communication technologies, this physical structure is bypassed. Precisely, the Industry 4.0 framework promotes the integration of key enable technologies such as Cyber-Physical Systems (CPSs), Industrial Internet of Things (IIoT) or Artificial Intelligence (AI) to materialize the convergence between operation technology and information technology, thus, leading to a new view on automation models and architectures.

In this regard, currently, a great deal of scientific and technical efforts is being devoted to review classical automation pyramid concepts and related industrial automation architectures. For example, as stated by H. Dibowski et al [1], in order to achieve better integration and flexibility in industrial production lines, the semantic linking approach between existing automation dimensions should be promoted. That is, leading to a modules relation approach instead of a complete integration or merging of existing modules. In this regard, the existing single modules will remain mostly unchanged, so it is easier to further develop and to maintain the automation architecture. Indeed, one of the main research lines pointed out by the Platform Industrie 4.0 Research Council about flexible, modular production systems and their architectures, is the proposal of the so-called digital twins [2]. That is, the proposal of virtual models including different dimensions of the industrial automation, so permitting advanced, predictive open and closed-loop control of technical processes and plants. Thus, preserving as much as possible the physical assets and their interconnection, but providing a logical layer from which optimized decisions are revealed.

Nevertheless, it is precisely in relation to such virtual models and industrial digital applications in general that there is a need to discuss new architectures to clarify how these models can communicate in standardized manner, how can be connected in real time with the physical information, how these models can be seamlessly integrated into the value chain, and which technologies are required in order to exploit the foreseen potential. There are some immediate benefits that IIoT, CPS and IA, as constitutive parts of industrial digital applications, can bring to companies, and especially to those focused on continuous decision-making. In fact, one of these benefits is the digital representation of the manufacturing's condition, its behaviour and integration with the production environment. Such a digital twin based approach would allow to check whether the operation of the assets, from the production point of view, is aligned with the expected key performance indicators [11]. The industrial sector is still at the beginning of the deployment of such technologies, which have a huge potential that companies, and especially the SMEs, have yet to realize. The consideration of digital application such digital twins in a flexible manufacturing process will bring opportunities to improve performances by making better decisions in advance, reducing inefficiencies, improving the performance of the machines, but above all, allowing an optimized control of the industrial production. However, an effective integration to make compatible current automation architectures running in the industrial sector with the required one, is still being explored through multiple scientific and technical initiatives. Two main challenges have to be faced to drive an operative industrial revolution. The first one is the collection of distributed plant's data and their subsequent organisation, since industrial assets taking part of a production line can be diverse in technology while their internal control loops must be preserved. The second challenge is the exploitation of data from the logic point of view, and the enabling of a process's flows to autonomously operate the manufacturing process as a whole [13].

In this regard, the responsibility of related public and private institutions as well as universities in promoting and enabling these advances is fundamental. On the one hand, promoting and encouraging research and development activities that make it possible to carry out technology transfer activities to SMEs. On the other, training professionals in the aforementioned technologies, who can bring these advances closer to society [3]. Aligned with such a situation, multiple Industry 4.0 laboratories are being developed from the Academia promoting new automation architectures to materialize the convergence between the operation and information technologies. These initiatives are critical to promote the digital transition of the industrial SME sector, such as Testlab (Swinburne and Auckland), ELLI (Ruhr, Aachen, Dortmund) [12] or AME (Coventry).

Thereby, the main contribution of this work lies in the design of an Industry 4.0 laboratory based on modern automation architectures inspired on the new trends in the sector. The design of the laboratory is carried out through an automation framework supported by an IIoT information exchange platform and distributed digital applications under the CPS concept. The implementation of the so-called I4Tech laboratory faces the current automation challenges related to the compatibility with the existing automation infrastructure, and the use of information technologies to improve, optimize and increase the functionalities of the industrial systems in a robust and modular way.

The originality of this work includes three main aspects. The first one is the approximation of the concept of REST application programming interface (API), a mature technology in IT environments, with the aim of generating an abstraction layer of OT assets, aligned with current trends in administration shells for asset management, as proposed by RAMI 4.0 [7]. Second, the effective implementation of a network of IIoT devices, industrial 4.0 assets, and IT applications at the edge and cloud levels. This approach makes it possible to extend the functionalities of the plant with a reliable implementation, providing new functionalities from IT to OT systems, mainly connectivity, communications and software, leading to a cybernetically secure but accessible cyber-physical system supported by Schneider Electric devices. Finally, the implementation of digital applications based on the technological pillars of Industry 4.0, that is, cloud computing, mobile devices, data analysis, artificial intelligence and augmented reality, have been done and validated.

The rest of the paper is organized as follows; Section II presents the new trends on automation models to substantiate the design of the structure chosen. Section III introduces the flexible manufacturing process in which the automation system is based. Section IV details the proposed automation structure, including the IIoT connectivity and CPS's logics. Section V presents the performance of the proposed automation structure. Finally, the conclusion is included in Section VI.

II. Automation Models in the era of of Industrial Internet of Things

The key aspect handling the complexity of industrial systems under the Industry 4.0 framework, is the consideration of automation models to structure and standardize functions, information, its exchange procedures and the interaction among subsystems. The classical CIM model exists in various versions with different naming conventions and numbers of levels, but it typically comprises four to six levels following a hierarchical approach highly influenced by the functional composition of a production system. Indeed, the so-called automation model 3.0 is based on isolated products and assets following a hardware-based structure with functions related to such hardware and a consequent hierarchical communication. The desired evolution towards the fourth automation model, promotes the product and assets as part of the network. Thus, leading to flexible systems and machines, distributed functions throughout the network, assets that can interact through all hierarchical levels and, in consequence, a potential communication among all elements. In this regard, cloud, fog and edge technologies promote such evolution from the classic approach in automation offering better integration of different automation modules and their functionalities [14].

Dealing with such evolution of the automation models, there are several initiatives that are being considered as references for their deployment at the industrial sector, such as the IIRA model [4], or the CPS architecture [8]. However, the Reference Architecture Model Industrie 4.0, RAMI 4.0, has perhaps the closest relation to production systems and has led to the first implementations [5]. The RAMI 4.0 is considered as a service-oriented architecture, where the so-called technical or active objects provide services to other components through communication protocols and through a network. The operation principles of this architecture are independent of manufacturers, products and technologies. In the Industry 4.0 framework, objects come from the information technology, such as models, algorithms or software procedures, and also from the operation technology, such as actuators, detectors or computers. In this regard, RAMI 4.0 provides a structured description of the main elements of an object using a three-dimensional model consisting of three axes: (i) the Layer axis, (ii) the Life Cycle axis and, (iii) the Hierarchy axis.

Thus, the Layers axis describes the architecture in terms of properties and structures of the system with its functions and specific data in the form of layers. Specifically, six layers are used to describe the structural properties of an object, from the Asset layer to the Business layer. The Life Cycle and Value Chain axis responds to the IEC62264 standard. It is used to describe an object at a particular point in time during its useful life, from its design, development, production and use, to its disposal. In this axis, the asset is characterized by its state at a particular time and in a particular location. Finally, the Hierarchy axis is based on the reference architecture model for a factory following the IEC 62264-1 and IEC 61512-1, which are, respectively, the standards for IT integration and control systems. To ensure consistent consideration in as many industries as possible, the terms Enterprise, Workplace, Station and Control device have been taken from the standards mentioned above and the axis have been extended to reflect the needs of the Industry 4.0 with the terms Product (to consider smart products), Field device (to complete the hierarchy), and Connected world (to consider a network of enterprises). Thus, the RAMI 4.0 can be considered as a 3-dimensional map where the Industry 4.0 deployments can be represented in terms of connectivity and interrelations among Layers, Life Cycle and Hierarchy. The availability of new technologies in the industrial scenario such as IIoT, CPS and AI, represents a huge potential to increase industrial efficiency, competitiveness and sustainability, however, a proper strategy is necessary. In this regard, the RAMI 4.0 model represents a key element to plan the evolution of manufacturing and supply chain of 4.0 assets

However, although such architecture shows a huge potential to materialize the required structure enabling Industry 4.0, there are just a few works showing a practical implementation, and even less considering the deployment of digital applications over an industrial manufacturing process.

III. Flexible Manufacturing Process at the I4TechLab

The scope of this study is aligned with the characteristics of the industrial automation laboratory on which the described implementations have been carried out, the I4TechLab shown in Figure 1. The industrial facilities consist of a set of conveyor belts specifically designed for the transport of trays over which the products are placed for their automatic or manual manipulation. Specifically, the flexible production process has the potential to manufacture different variants of product, starting all from the same initial material. That is, leading to a small-scale flexible production process in which components, like metallic or plastic based pieces or electronic devices among others, can be routed by different paths in order to result in variants of the same product (e.g. differences in assembling, machining or labelling processes).

From the automation point of view, the manufacturing process is composed by six main workstations: (i) the material input station, (ii) the finished product output station, and (iii) an accumulator station for storing trays, and three additional workstations emulating processes over the input material, that is, workstation 1, workstation 2 and workstation 3. Thus,

Fig. 1. I4Tech laboratorie facilities.

considering availability of input material and the corresponding production order, the conveyors systems moves the products at the desired processes. Stoppers and platforms are used to manage the flow of trays throughout the process, avoiding collisions among them and driving the desired path for each tray, since the conveyor belt motors operate continuously at a fixed speed. The operating principle of stoppers is made up of three different states, which can happen simultaneously, further described on Figure 2:

REST: The retainer is in "Rest" state when the system starts, and whenever it does not have a waiting tray, so it is awaiting the arrival of one.

READY: When it detects a tray on the sensor, the stopper changes to "Ready" state. It will remain on the same state, blocking the tray movement, until some conditions are achieved. First, the stoppers have a locking interface to allow upper control systems to manage tray flow, so it must not be locked. Also, the destination stopper must be in REST, and it must not be receiving any other tray from other paths.

MOVE: When the conditions are meet, the stopper goes to "MOVE" state, the PLC deactivates the stopper actuator, allowing the tray to move forward. The algorithm used can be generalized to carry with N different advance path, although only $N = \{1, 2\}$ exist on the I4Tech facilities.

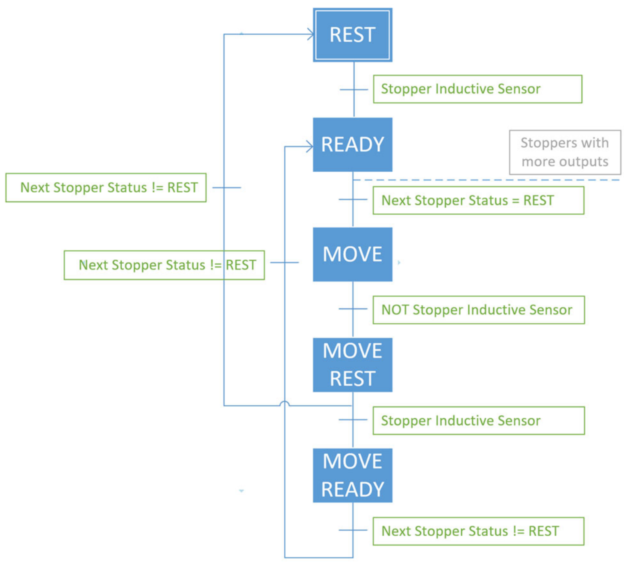

Fig. 2. Stoppers logic grafcet diagram.

Once the retainer is in MOVE state, the tray is released and the necessary conveyors are activated. Thanks to the geometry of the stoppers and trays, once the tray has moved a few centimetres the sensor detects it, and after a few milliseconds the stopper can return to REST, with the MOVE state activated simultaneously. This behaviour improves the trays rotation, decreasing the death times, while REST and MOVE states remain active at the same time, becoming a new state. The REST-READY transition logic remains the same, so when a new tray arrives the stopper changes to READY state, becoming another compound state. To fit the correct behaviour of the stopper the READY-MOVE transition must also care about this compound states, that is, the stopper must not change from READY-MOVE to MOVE. In such state, the stopper first must change to READY state before being able to go to move state again, ensuring that there is not any tray in the path.

To be able to carry out complex manufacturing processes it is essential to know the position of the trays at all times. In this system the tracking can be carried out by software in a kind of inertial integration. With a dedicated data structure used to encapsulate all tray information required, it can be tracked by software looking at how the trays are moved by the stoppers. With the state information of the stopper, how the trays are moving can be precisely known, so by updating trays position following the behaviour of the stopper as the system evolves, the tray position can be known at any time. As the system state is discrete there is no measurement error, so that method can be used as a long-term tracking system. The algorithm has been tested in previous work experiments to ensure its reliability.

IV. I4TechLab, Design and Implementation

The implementation of an industrial automation architecture following the expected Industry 4.0 functionalities has been approached through three main stages: (*i*) object oriented programming at operation technology level, (*ii*) industrial API as administration shell, and (*iii*) deployment of digital applications. Thus, through these three stages, it has been possible to evolve towards an Industry 4.0 scenario in which the traditional CIM architecture remains as well as the digital transition is materialized. A general description of the main items of the implemented architecture is shown in Figure 3.

A. Object oriented programming for operation technologies

In the specific industrial case at hand, the stoppers have an apparently simple behaviour, that is, they block the movement of trays, with the objective of avoid collisions and control

Fig. 3. I4Tech laboratory cyberphysical system diagram

trays path, and also, by its state change, trays information has to be updated to track its position. An object-oriented program structure has been proposed for the stoppers control, where each of the stoppers of the system is instantiated as an object that handles its behaviour. The implementation has been carried by "Function Blocks", which have many limitations to implement a complete object oriented paradigm, but can be adapted to handle the same philosophy with several limitations [9]. By this way, the PLC software is much more flexible to changes on the hardware needs, moreover, code reusability is highly increased, improving the scalability. Achieving a software with these characteristics, that is, based on the stopper FB, handling the management of the system inputs and outputs, would allow us to adapt the machine behaviour to the requirements of the operation, for example adding more types of products, changing the locations of the stations or completely altering the operating principle of the machine, always maintaining the same structure of stoppers control, modifying just the flow of these through abstract control variables or changing the connexion between stoppers. Is in this way that we obtain a scalable flexible manufacturing system, enabling also a fast deployment of new facilities with similar architectures with much lower complexity.

The basic object around which the entire program is based has been designed to handle all the use cases required. Because of the limitation of FB, which do not have polymorphism and inheritance characteristics (at least on typical PLC implementations), it is the most maintainable and scalable way to achieve our objectives avoiding code duplication, at the cost of increasing resource usage [10]. Stopper object is designed to model a two input paths and two output paths, even though that use case does not exist, is the only one that can be used universally on our facilities. The stopper object implements the algorithm described on Figure 4, which is the responsible of avoiding collisions, define stoppers state and handle sensors and actuators. It also implements the tracking algorithm described on the last section. Each stopper instance contains three buffers to store tray information, one to store information of the tray that is being locked by the stopper (if there is not any tray, the buffer is void), and other two to store the information of moving trays, one for each output path. If there is a tray waiting on the stopper, when it changes from READY to MOVE, the stopper moves tray data from the input buffer to the desired output buffer of the chosen path. When the tray has arrived to the destination the stopper moves the tray data from its output buffer to the destination input buffer.

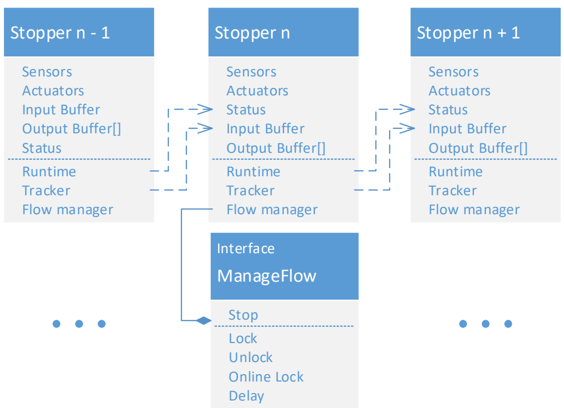

Fig. 4. Stoppers interoperability diagram

For the implementation of the plant, all the stoppers have been instantiated and the interconnection described on Figure 4 has been used, describing the topology of the hardware in the I4Tech facilities. Furthermore, a flow management interface has been designed to control the path of the trays in the cell, becoming the stopper object and abstraction of the automated conveyors system, enabling higher level applications to modify the path of the trays, and being possible to change the hardware topology without going deep in the operation technologies complexities, that is, sensors and actuators safely management. Finally, a simple upper-level application has been developed in the OT platform. It defines some of the business logic behaviour (production process), that is, the software that handles the tray flow to make a production process. It consists on a set of rules which define the behaviour of the stopper where a production process has to be carried out, and also the behaviour required for the bifurcations.

This methodology would be the most similar to the object-oriented programming paradigm that can be implemented in PLCs, even with impediments that do not allow to assume all the usual characteristics of these but being useful for the proposed objectives, reducing the effort for the development of a reliable control system of the low-level requirements of the process. As mentioned above, the use of object-oriented programming paradigms is key to providing flexibility to production systems, mainly thanks to the ability to provide abstraction of the functionalities of an existing element with respect to the technical difficulty that these present. The software exposes the necessary element, presented in a synthetic way, which allows the handling of the object in the desired way, avoiding the reprogramming of its fundamental functions of operation and easing the integration with upper architectures. Thus, easing the integration of the Administration Shell concept.

As described in the following sections, the described abstractions would be also available to other actors of the CPS but also exposes some process functionalities, like M2M interactions with other machines related to the asset, production system behaviour enhancements or process control. In the developed architecture some virtual assets have been used to explore M2M functionalities, like simulated processes that happen on the industrial cell.

B. *Industrial API as Administration Shell*

The proposed automation architecture to be deployed in the I4TEch laboratory is based on the concept of API REST, a very established method in the field of IT, implementing the concept of Industrial API. In this particular case, through the API, the integration of the cell in a cyber-physical system results in a simpler and more reliable task. It allows simplifying the implementation of 4.0 technologies on the plant by introducing digital services from the IT point of view. It allows the use of an interconnected multiservice system, also enabling machine-to-machine communications over modern protocols even with the existing hardware.

For the proposed solution, an edge computing model has been considered, restricting the use of the OT protocols, e.g. Modbus TCP/IP to the secure LAN networks, also reducing response times and network saturation. It also allows the implementation of secure communication structures through routers and firewalls. In the developed architecture three different technologies have been implemented, each one contributing with its own characteristics: (*i*) HTTP (Hypertext

Transfer Protocol), (*ii*) MQTT (Message Queuing Telemetry Transport) and (*iii*) OPC UA (Object linking and embedding for Process Control Unified Architecture), which are further described on Table I.

TABLE I. PROTOCOLS CHARACTERISTICS

Protocol	Functionalities
MQTT over TLS	Publisher – Subscriber architecture (tell do not ask) HTTP URL – Topic compatibility High flexibility – REST API
HTTPs	IT standart web protocols High compatibility with IT and web browsers High flexibility – REST API PubSub MQTT based over WS
OPC UA	Next generation industry standar Information modeling principle PubSub MQTT based

The proposed methodology for the implementation of this industrial API has been defined taking into consideration the challenge of the current professional sector. That is, there is a significant gap among professionals around the required technologies, knowledge and skills related to industrial IT.

For that reason, the Industrial API has been developed over Node-RED. It is a runtime based on JavaScript, designed to run software developed in a low-code graphical programming language, with a flow-oriented paradigm, and also a web-based graphical user interface to "draw" the software and manage applications, which are named "flows". Its deployment is carried out over an Edge Box IIoT device, an industrial miniature computer supplied by Schneider Electric, which build-in support for Node-RED. JavaScript is known for its events orientation, and Node-RED is designed to develop event-driven applications, either based on time, external triggers or conditional events, becoming a flexible and powerful tool for the IAPI. There are other alternatives to Node-RED, with similar characteristics, but there are mainly three incentives for the selection of Node-RED, that is, it is an open source software, there is an active and evolving community and there is professional support from sector leaders as Schneider Electric.

Node-RED runtime embeds all the low level requirements of the OT system, encapsulating the particularities of the control system integration and industrial communications, exposing the asset administration shell in I4.0 compliant communications. A complete industrial control system has been defined in the particular case of the I4Tech laboratory, focused on the digitalization and integration into cyber-physical system from the bottom up, but it has to be noticed that the proposal is suitable for any existing industrial OT system, enabling the introduction of CPS and Industry 4.0 in SME. The integration of digital applications services can be integrated in business logic services, Node-RED based applications, which interact with the asset administration shell, which creates an abstractions layer that simplifies the implementation of high-end applications at upper layers. The interaction with the OP system has been designed to be resilient to API disconnections or communication interruptions by design, avoiding process errors or security problems, which are well managed by OT technologies. In scenarios where time-critical applications need to be controlled, RTOS based implementations of the proposed Industrial API could be used.

C. *Digital applications as Industry 4.0 cloud services*

The proposed IAPI architecture and components enables the deployment of CPS interacting with OT assets. Two examples of such digital applications are described below.

1) *Industrial Computer Vision as a Service based on AI*

Computer vision is a classical technology, with multiple applications in the industrial sector, and widely used, for instance, in quality control applications. A great deal of computer vision standalone and/or embedded solutions are commercially available at the OT industrial level. Such products are often based on a specific configuration software which allows the design of the required image processing to achieve the desired behaviour, like Keyence XG-7000 vision systems. In the last decade, however, with the aim of incorporating algorithms that can obtain a high-level of understanding from digital images or videos in industrial environments, capture methods, analytics algorithms and processing power have received a lot of attention from the technical and scientific community. The improvements in high bandwidth parallel computing technologies, like GPU or TPU, and the availability of new machine and deep learning algorithms, are promoting a new trend in image processing methodologies.

The novelty of the proposed application is aligned with current trends in the sector through the implementation of a computer vision system for ICS based on machine learning algorithms and deployed under a Software as a Service (SaaS) architecture. The application has been implemented following the architecture depicted in Figure 5. In the I4Tech laboratory, the computer vision camera is based on a Raspberry PI single-board computer and a Camera Serial Interface (CSI) compatible module, which exposes a REST API that can be used to shoot a picture, but the application could be compatible with other existing industrial lead products. The application manager consists on a Node-RED based server, which handles required integration logic in the context of the I4Tech laboratory. It implements the logic for the information routing among the different services, the OT systems through the API and the external services by secure communication channels. Finally, the computer vision service is a cloud based Matlab Processing environment, Matlab Production Server (MPS), which is responsible for the execution of the Matlab based algorithm designed for the proposed task.

The objective of the implemented processing service is to count the amount of products in the captured picture, detecting three different predefined shapes [7]. The processing algorithm is composed by three different stages, the first one dedicated to image pre-processing with the objective of binarize the image, a second stage that performs a feature extraction of the image, carried out by "*regionprops*" functions from Matlab Image Processing Toolbox, and finally a ML classifier, in this case a random forest algorithm [6].

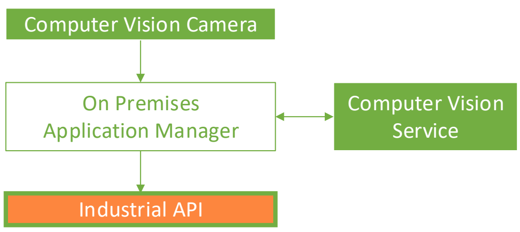

Fig. 5. Industrial API interface structure.

Results of the data are then fed into the Industrial API service, which aggregates the data with the OT system information and manages its storage. Thus, the application is designed to generate information about the products in the manufacturing process. The information is used, at this moment, for statistics purposes.

The described application demonstrates the benefits of the proposed structure. Architecture, protocols and software are based on mature standards in information technologies, allowing high compatibility with modern IT systems. In our opinion, an easy integration of the proposed architecture in IT environments is achieved, being able to apply web-based technologies solutions on the edge in industrial environments. It eases the transition to cloud-based computing structures, enabling SaaS structures and offering alternatives to improve scalability and reuse of software and computing resources. The use of containers and Git enabled solutions, like Node-RED also brings advantages in terms of maintenance of the software, dependencies updating and security vulnerabilities scanning. Simple and reliable encryption, certifications and authorization solutions are available in the market, highly automated, reducing the technological gap between OT environments and cybersecurity solutions.

1) *Production Control system based on AI*

An artificial intelligence-based control system has been proposed to optimize production decisions in the I4Tech laboratory. There are multiple techniques for the optimization of decisions in the field of manufacturing control, but the use of machine learning technologies is still far from being a reality for SME. Control systems are usually left to rule based logic or regulation theory based algorithms. There are also solutions of decision support systems based on AI and big data, which help in management tasks for manufacturing, processing or logistics environments. However, the use of AI for the optimization of low level decisions in ICS is still far from the manufacturing industry. In this regard, a closed loop control for OT systems based on information technologies and artificial intelligence has been deployed as an application in the I4Tech laboratory. The application has been designed to be deployed with the same architecture described in the previous application, with the particularity that in this case the Application Manager also carries the execution of the desired control action by the IAPI methods described in Table III.

Figure 4 describes the different items which compose the designed application. The application manager is the service dedicated to manage the asset API, it is responsible of (*i*) listen to the asset to check if a new action is required (by MQTT subscription), (*ii*) collect all the required data for the execution of the algorithm (throw the HTTP data API), (*iii*) call the execution algorithm by the core REST API, and finally (*iv*) send the action to the industrial asset by the Industrial API. That software has been also deployed into the same service which handles the previous application, placed on-premises with an Edge computing architecture. The algorithm core application is composed by a feedforward neural network classifier, which has been designed and trained to estimate, as input, the ICS status, and three class outputs indicate the optimum product to be produced. There are multiple alternatives to the proposed architecture, but usually with higher computational cost and time consuming. The objective of the application is not only the implementation of a control service, but to demonstrate the suitability of the proposed automation architecture to accommodate such algorithms in industrial applications.

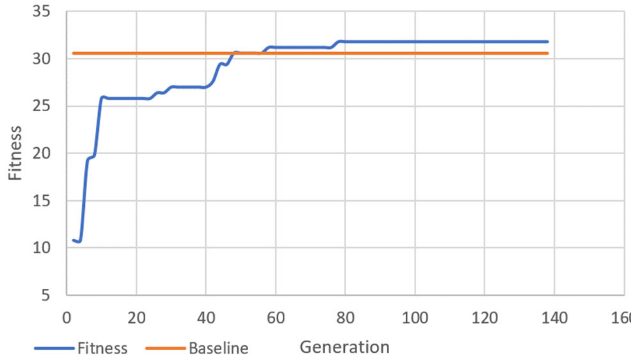

Fig. 6. Algorithm training fitness

As can be seen on the Figure 6, the model performance is measured by a fitness function designed for the process to be studied, considering the productivity in time and the resources consumption. On each generation with mutations that improve model performance. The application described is another example of the advantages described on the previous section. This example focuses on showing the potential application and deployments possible, enabling, for example, machine optimization with cloud services supported by the supplier, with its own know-how, thus increasing the scalability of such IIoT applications.

V. Discussion

The proposed automation architecture, based on the REST API concept allows a simpler approach of 4.0 technologies to the industrial environment, specially the one that can be found in the industrial SMEs. The applications described above as examples of industrial digital services, together with technologies such as Node-RED, represent tools and an architecture with the potential to be industrialised.

From our point of view, the most important potential lies in creating interfaces that generate abstractions from the OT complexities of the plant, a concept widely developed in IT systems, but little valued, for the moment, in the software used for ICS. In addition, the use of independent services to implement these interfaces makes its approach to current industrial control systems easier, reducing the knowledge and investment barriers of the SMEs to a feasible implementation of Industry 4.0.

On the other hand, the use of graphical programming languages, no-code style, induces a problem which is characteristic of ICS, the lack of scalability and reusability. Even though there are tools and mechanisms to solve it, the use of graphic languages is associated with that problem. It is also an intrinsic problem in the sector due, in part, to the poor replicability of such systems. In any case, it allows an approach to current industrial environments, in which languages such as JavaScript, Python or Java, with harder learning curves, would slow down the use of these technologies.

Reliability and safety aspects caused by such systems must also be taken into account, being a fundamental factor in the design to avoid economic, infrastructure or personal damages. In this text, a complete vertical IIoT structure is proposed, from low-level PLC software to cloud applications, creating a system composed of multiple services but which at the same time must be resistant to the failure of some of these. It has been achieved to ensure an always safe operation of the physical elements of the system by duties segregation, ensuring that each element knows what has to do to work safely at the edge. This is one of the main challenges of such architectures, and it will require an appropriate design depending on the context.

Finally, another factor to take into account in the context of Industry 4.0 and the technologies mentioned on this text, cybersecurity. Protocols such as MQTT, HTTP and OPC implement accredited security standards, such as SSL or authentication mechanisms based on credentials and external services, but their practical implementation in industrial environments of SMEs still presents challenges and difficulties to take into account. Moreover, unknown underlying vulnerabilities in the hardware or software used can also be a risk, as well as zero-day vulnerabilities not discovered yet. These effects are aggravated by the low concern about the update of software in such environments, and the increase in devices with connectivity, thus increasing the attack surface.

VI. Conclusions

In this paper, an I4Tech laboratory is presented as an integration environment between operating technology and information technologies, based on the concept of Industry 4.0. The described laboratory allows to identify challenges that must be studied regarding the interaction mechanisms between different applications and industrial actors, pushing on the industriability of the IT technologies toward current industrial OT context. It also offers a controlled test environment for the development of intelligent applications, close to a real industrial context regarding hardware, architecture, communications and security, allowing to evaluate the difficulties that all this entails. In addition, being located in an academic environment, it enables an active learning environment in Industry 4.0, where industrial SMEs can assess and validate technologies and applications related with the new trends in digitization.

About the industrial asset, the approach proposed for the development of OT control systems makes the software more flexible to the system requirements, increases the scalability of the software and eases the integration with other application by the abstraction of the operation complexities. The Industrial API proposed, which is based on mature information technologies, gets close to the Administration Shell concept from RAMI4.0. The proposed methodology also is and the implementation on the I4Tech laboratory demonstrates its viability. It could be adapted to any kind of OT system, becoming an abstraction layer which eases the deployment of Industry 4.0 applications.

Finally, highlight the advantages offered by the architecture proposed in this text, scalability, maintainability, proximity and compatibility with information technologies, enabling the use of IT tools and resources in industrial environments, such DevOps, CI/CD, git, etc. This work demonstrates how the use of APIs that create abstractions of OT environments facilitates the implementation of 4.0 technologies in industrial environments. Furthermore, with the proposed approach, the barrier to entry for SMEs is reduced. This API-driven approach has already been established as a tool to be used in industry 4.0, for example, in the form of a REST API, although the use of frameworks such as OPC UA [7], and as it can be seen in this work, the use of MQTT, widely used in IoT and IIoT [14], also generates important advantages.

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