Design of a multi-sided platform supporting CPS deployment in the automation market

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***Abstract*— CPS technologies are already mature at European level, but adoption in small & middle enterprises is constrained by a still emerging value chain and by the challenging transformation of manufacturing processes that their deployment in a manufacturing system requires. As a matter of fact, the CPS growing market potential is scarcely supported by tools able to sustain the solid ecosystem required for a relevant market uptake. This issue becomes even more constraining the moment the concept of CPS is extended and aggregated to propose cyber-physical machines and manufacturing systems, where the complexity of the controlling intelligence and of the digital counterpart explodes. This paper aims at describing how the design and implementation of a multi-sided platform (MSP) for CPS deployment within the automation sector can provide the technological background to incentivize their adoption. In fact, the market needs an economic support to accelerate the transition towards new paradigms for the development of the software components of a mechatronic system. Developing an infrastructure on the top of which the CPS value chain can be instantiated and orchestrated, we provide the technical means to incentivize the creation of such an ecosystem able to support SMEs in their transition towards Industry 4.0.**

Keywords—Multi-sided platform; Factory automation; IEC 61499; Digital Twin; Business model for multi-sided platform

I. Introduction

The world of industrial automation is undergoing a major transformation: the shift towards mechatronic and cyber-physical systems means that manufacturers are no longer constrained by the mechanical design of a machine. When applying the concept of CPS to manufacturing we need to consider the evolution of machines and production systems, throughout the last decades, from almost purely mechanical equipment to reach the current understanding of mechatronic apparatus. The introduction of the PLC (Programmable Logic Controller) technologies in the 80s democratized the possibility of "programming" the behavior of a system in addition to its mechanical properties, and this triggered the birth of a new generation of shop floors. Machines are becoming able to provide significant opportunities for flexible manufacturing, adaptive throughput, energy management and machine lifetime value, by adapting their manufacturing behavior harnessing the far greater flexibility provided by software controls [1].

Now we are on the verge of seeing the fusion of digital technologies with the manufacturing environment, with complex mechatronic systems capable of using their on-board intelligence to extend outside of their physical boundaries, and this means that a new generation of PLC is equally needed to support this transition: the embedded intelligence of a machine is not anymore just the executor of a control logic but also the "gateway" towards the cyber domain.

The connection of machines with their digital counterpart is indeed becoming an essential requirement for the lifecycle management of mechatronic systems [2]. The Digital Twin, a concept borrowed from space programs where simulation of the systems is mandatory to ensure any change produces the desired effect, is indeed becoming a strict requisite providing engineers with the opportunity to address any undesired effect before applying the changes to the system in operation. This concept has been nowadays broadly extended to support products/systems design, virtual commissioning and the optimization of manufacturing lines installation & ramp-up [3], [4].

As the ongoing industrial revolution has been largely recommended as the driver for reshoring manufacturing within Europe [5], sustaining the transition towards the CPS concept of Industry 4.0 is mandatory. To reach this objective, new technological and methodological approaches able to support companies in their evolution, must be developed. Indeed, if giving a substantial advantage by providing the means to improve the overall manufacturing environment, Industry 4.0 also poses a severe challenge in terms of investments, update of employed hardware and review of production strategies. Companies need to be guided in this transition by providing not only financial incentives, but also a rich environment able to accompany them in technological update and plants improvement [1].

Aim of this paper is to present a technological infrastructure, namely a digital marketplace, conceived with the aim of creating the ecosystem for the concurrent integration and market deployment of mechatronic systems, CPS and virtual twins. In order to manage the arising complexity of involved systems, we build the platform on the top of the IEC-61499 standard, as currently in the best position to play the pivotal role in enabling the deployment of distributed and intelligent systems [6].

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II. THEORETHICAL BACKGROUND

A. Advancements of distributed automation systems on the top of IEC 61499

During the last 20 years the standardization and research efforts related to control software for industrial automation was focused on improving quality and reliability while reducing development time. Even though distributed automation is considered a fundamental innovation of Industry 4.0, the current automation paradigm, based on the use of programmable logic controllers (PLC), according to the IEC 61131-3 standard, is not suitable for distributed systems [7].

The reasons for this inadequacy are mostly historical and technical: PLCs were created to manage the execution of real-time feedback control loops, within the time domain. To optimize their effectiveness and guarantee their performance, their paradigmatic approach has been focused on the concept of "time-cycle" and, equivalently, also the programming languages of IEC-61131 are all designed to implement time-based control logics. The issue now generated by the "digitizing industry" trend is that we are trying to bridge together two domains – time-cycle-based of control and event-based of services – that use different paradigms.

The IEC took this into account for the development of the IEC 61499 architecture to support such new features of next generation industrial automation systems as distribution and reconfiguration [6], while offering modern platform-independent approach to system design, like the Model Driven Architecture [8]. Another of the most relevant goal of IEC 61499 was to promote the development of heterogeneous systems composed of control devices of different vendors; in fact, the standard defines a flexible and extensible mechanism of compliance profiles, allowing its extension to different needs. Thanks to this, Chouinard et al. [9] reported on implementation of a distributed system of 70 controllers demonstrating hard real-time operation when communicating over Ethernet; Yan [10] presented a baggage handling system implementation with a few hundreds of composite function blocks deployed across 50 controller nodes communicating via Ethernet; NxtControl [6] demonstrated in 2010 a Delta robot prototype fully controlled with the IEC 61499 technology using distributed control hardware of Siemens, Beckhoff and Wago .

In supporting the transition towards CPS in manufacturing, the event-based nature of the standard is what simplifies greatly the integration with the Digital Twin of the mechatronic system, thanks to a coherent approach to object orientation in software programming.

B. Integrating the Digital Twin in the deployment of Intelligent manufacturing systems

The Digital Twin is an exact representation of real assets (even before an asset is built physically) created collecting and synthesizing data from various sources including physical data, manufacturing data, operational data and insights from analytics software [11] . It is an evolution of the digital product (created by CAD or CAM tools) so that process and transformation can be tested and verified in order to avoid problems or mistakes that could cost money and cause delays in delivery. Developments of complex products and processes requires the support of software tools in order to see how the final system behave[12]. The availability of a Digital Twin of a system or of a whole factory allows forecasting the performance of different scenario. Nowadays systems are complex and need to change quickly, and it is not feasible to create and maintain an analytical model that can completely capture all the complex interactions of different component of the system: the Digital Twin can reproduce the complex system and its interactions in a virtual environment [13]. It is possible to apply optimization algorithms on different configuration of the virtual environment, changing the boundary conditions and letting the system evolve in the same way the real system does [14]. A Digital Twin enables companies to better understand and predict the performance of their machines during all the factory lifecycle [15]. Data is generated in real time, and this helps businesses in better analyze and predict the problems in advance or give early warnings, prevent downtime, develop new opportunities and even plan better products for the future at lower costs by using simulations. All these will have a greater impact on delivering a better customer experience in business as well. Digital Twins are a key element in Industry 4.0 enabling the exploitation of Big Data, Artificial Intelligence (AI), Machine Learning (ML) and Internet of Things. The key factor for successfully exploiting Digital Twins is the support of the machine and equipment manufacturer or supplier, to create a digital copy that, knowing the internal system design, can mimics its real behavior. Another key factor is the continuous synchronization with the physical world exploiting existing data in highly automated equipment or taking advantage of the widespread usage of the Internet of Things that have made adding sensors more cost-effective and accessible.

C. The taking-off role of digital platforms in boosting industry digitization

The growing interest demonstrated towards digital platforms by European Commission and industrial players, showed the potential of these instruments of becoming the drivers for industrial transition towards Industry 4.0. The platform revolution began in the business-to-consumer (B2C) area through eCommerce, FinTech and sharing economy business models and is now expanding into the business-to-business (B2B) space with innovation based ecosystems and data-enabled business models. This is mainly driven by companies shifting their focus from selling products to offering performance based services through digital platforms, creating a new way of organizing, managing and distributing added value products & services by means of matchmaking customer needs with product/service providers [16]. In literature, a univocal definition for digital platforms is not present: two of the most reflecting the market evolution describe them as "business models that allow multiple sides (producers and consumers) to interact by providing an infrastructure that connects them" [17] or, considering their role of mediators among contractual parties, as "a governance structure that determines who can participate, what roles they might play, how they might interact and how disputes get resolved" [18].

Platforms are nowadays present in different and variegate industries, in particular in high-tech businesses driven by information technology. Microsoft, Google, Intel, Qualcomm and Cisco are only few of the hundreds of companies that based their business on reducing transaction costs and facilitating exchanges by relying on digital platforms [19].

The value delivered through these kind of platforms can derive from a simplification of transactions between stakeholders, or by providing services or products on the top of technological building blocks used as a foundation. According with Evans & Gawer [20], in certain cases Multi Sided Platforms can play both roles, facilitating exchanges or transactions between different users, buyers, or suppliers relying on a product or technology provided as foundation.

As mentioned, while the consumer sector is already populated of platforms providing product/services in several market domains, the industrial market is still lagging behind. European Commission, in its "Digitising European Industry[1]" program, is pushing the development of digital platforms by financing projects that, at different levels, are meant to populate the European Digital Market with the technological and infrastructural incentives required to sustain industries. With these actions, EU Commission aims at filling the current gap that sees the lack of an holistic approach across value chains, able to bring together manufacturers, manufacturing equipment suppliers and IT companies, and give them the infrastructural support for test beds and demonstrators [21].

In the automation domain, where systems improvement cause the need for keeping well-established parts of existing systems and finding a way for integrating new ones [22], the access to technologies, infrastructures and skills is essential.

In the following section, we describe the marketplace developed for the DAEDALUS[2] digital platform able to match-make the stakeholders involved in the automation ecosystem, with particular reference to the adopted software infrastructure and the process management strategy.

III. A DIGITAL MARKETPLACE FOR THE AUTOMATION DOMAIN

The main objective of the proposed Digital Marketplace is to become the one-stop-shop for CPS(s) developers/manufacturers interested to sell their products via a unique, structured and safe selling-point, able to match-make product offer with plant owners, equipment manufacturers or system integrators needing their solutions.

In this context, the CPS has to be considered not only as a mechatronic system, but as a set of products (Hardware, Software and Digital Twin), which presence on the digital marketplace represents a potential way to better reach customers. Thanks to the nature of the IEC 61499 the platform relies on, CPS(s) and mechatronic systems may be controlled by different intelligences, potentially realized by different developers. The decoupling between the mechatronic system and the control application represents a big opportunity for developers who want to create their own control application. For that reason, each CPS needs to be accompanied by its digital counter-part able to replicate, in a virtual world, the CPS behavior.

To this end, the Digital Marketplace is not just a CPS repository, but it also provides a set of services enabling developers and manufacturers to test and validate their own products: the Digital Twin plays an important role during the validation process managed by the Digital Marketplace. Thanks to this process, the Digital Twin (hosted with the CPS into the marketplace) can simulate the mechatronic system in a well-know and certified simulation environment. This validation service can, in part, certificate the CPS capabilities declared by the developer during the product submission process especially for the logics and functionalities that stays behind the CPS. The digital twin, simulating the CPS behavour in a virtual environment, wants to provide a digital way to validate its cyber part. Therefore the aim of the validation service is not to test the CPS hardware part (widely tested by third-parties) but is to provide a well-structured testing protocol able to validate the CPS functionalities without the need of its physical part.

A. Marketplace architecture

In order to better understand how the Digital Marketplace manages the previous mentioned processes, the here presented diagram (0) is meant to describe the marketplace architecture in terms of software components, exposed interfaces and interaction flows. The Digital Marketplace is a web based application which exposes a set of web services that allow external components, such as portals, IDE, applications etc. to be connected with the Digital Marketplace and exploit its provided functionalities.

The fundamental layer, on which the rest of the architecture is based on, is the *Persistency Layer* which is composed by the repositories and the *Persistency Manager*. The *Repository* represents the knowledge base of the Marketplace and it's composed by the hosted CPS(s), the *Economic Data Model*, meant to describe all economic aspects of the products (pricing strategies, fees, etc.) and the *Semantic Data Model* meant to characterize the submitted product in order to be accurately searched and identified. The *Semantic Data Model* is managed by the *Product Manager* component which is also in charge to provide discovery functionalities of the hosted products.

The *Submission Manager* is the software component in charge to regulate the CPS submissions process starting from the request, passing through the validation, till to the payments. Both the payment service connector and the validation manager are directly connected with the product manager.

The *Validation Manager* has the aim to validate all submitted products in terms of provided functionalities.

The high-level component belonging to the Digital Marketplace is the *User Profiling Manager* which is in charge to manage the user profiling in terms of roles, authentication and authorization.

[1] https://ec.europa.eu/digital-single-market/en/policies/digitising-european-industry, last access on 31.01.2018

[2] DAEDALUS project, H2020 grant agreement No 723248

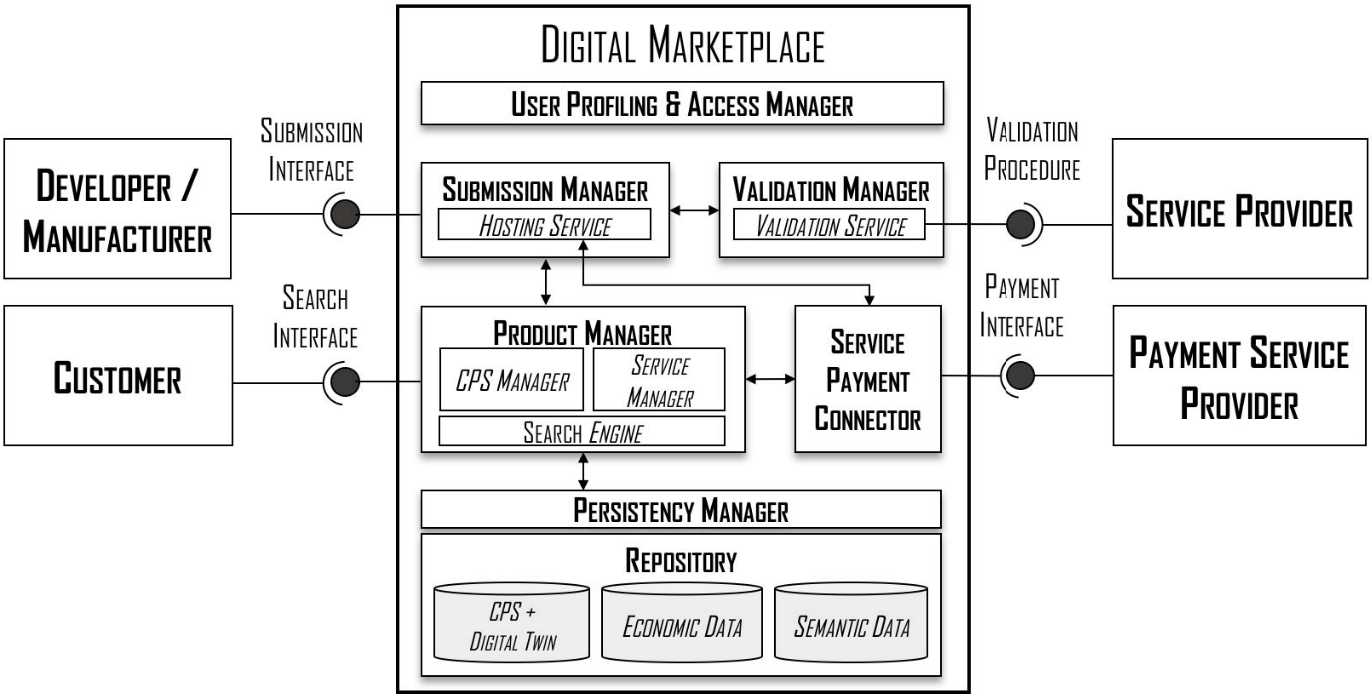

Fig. 1 Digital Marketplace Architecture

B. Marketplace processes

Taking in consideration the overall system architecture presented in the section before, the main processes, which the Digital Marketplace is in charge to manage by, are:

- *CPS submission process* meant to manage the entire submission process of a new CPS (included its digital counter-part) starting from the submission request, passing through the CPS validation, till to the release of the contract.
- *CPS certification/validation process* which is meant to validate the functionalities provided by the CPS.
- *Customer CPS request process* which represents the sequence of activities that have to be performed in order to allow, the Digital Marketplace customers, to discover the products.

These processes involves different actors with different roles: (i) the developer/manufacturer, which represents the creator of the CPS (and its Digital Twin); (ii) the Digital Marketplace which represents the main software component in charge to manage the logics that stay behind the here describe processes and (iii) the Certifier which is in charge to release the CPS certification.

The submission process (0) starts with the CPS' submission request made by the developer or manufacturer who wants to make the created product available through the Digital Marketplace. The submission request has to accompanied by the selection of the hosting contract where the developer/manufacturer selects the options of the hosting service and specifies which kind of validation/certification he wants to include.

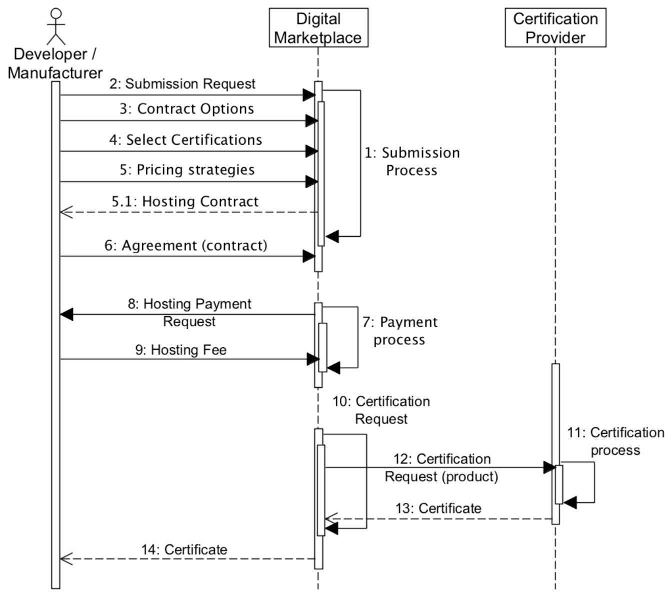

Fig. 2 CPS submission process

The nature of the contract establishes the rules that regulate the economic relationship between the developer/manufacturer and the Digital Marketplace in managing the CPS hosting. The configurability of the hosting contract allows the developer/manufacturer to select which kind of options he wishes (i.e. based on how long the application is valid, or based on the number of updates made available by the marketplace during the hosting period, etc.). The definition of the pricing strategies, as part of the submission process, allows the submitter to specify how the marketplace will manage contracts of the products usage between the marketplace itself and the customers.

Once the Digital Marketplace accepts the submission, it sends back to the developer the hosting contract that needs to be accepted: if accepted, the developer has to pay the hosting service in order to allow the beginning of the validation process where the submitted CPS will be tested.

The certification provider is a service meant to validate the functionalities provided by the CPS, defined by the developer/ manufacturer during the submission process. The certification process (0) consists on to simulate or test the Digital Twin of the submitted CPS into a simulation/testing environment, specially built by the certifier, where both the context of execution and the CPS' operations are replicated. The validation process follows a well-define protocol based on objective criteria, aimed to verify if the CPS specifications/functionalities, under certain conditions, are satisfied or not. In order to guarantee the tests repeatability, the CPS tester must publish, into the Digital Marketplace, the testing result accompanied by the applied testing protocol.

Once the CPS has been successfully submitted and validated, it becomes available to customers who want to buy and use it. For this purpose, the Digital Marketplace provides a search engine mechanism based on a set of algorithms meant to result the best possible answer to a search query. The aim of this semantic search is to improve search accuracy by understanding the customer's intent and the contextual meaning of terms as they appear in the searchable dataspace, within the system, to generate more relevant results. Semantic search systems consider various points including context of search, intent, variation of words, synonyms, meaning, generalized and specialized queries, concept matching and natural language queries to provide relevant search results. The semantic search will produce a result containing the list of suggested products which characteristics answer the customer's needs.

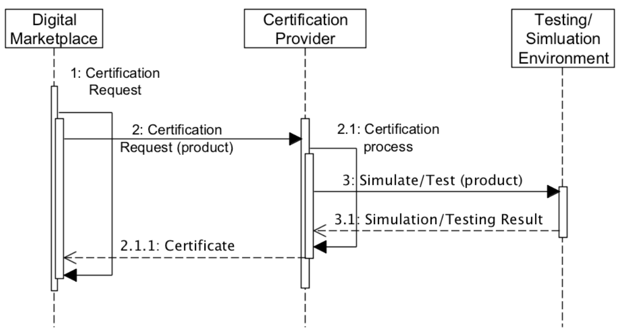

Fig. 3 Certification Process

C. Digital marketplace value creation

The proposed architecture has been developed in order manage the matchmaking of the manifold stakeholders pertaining to the automation value chain. The marketplace creates the value not only through the creation of a business layer among scattered industrial parties (i.e. matchmaking functionality), but also providing services that answer to the requirements of the fast-changing manufacturing environment (management of multiple applications related to the same HW device, management of Digital-Twins, enabling of product certification mechanisms, etc.).

The stakeholders involved in such mechanism have been aggregated according to 3 categories, namely Customers, Developers/ Manufacturers and Service providers, that reflects the main players of the automation domain. Few of them can access the marketplace with more than one role, for instance having the need to be a customer (system integrator that requires a control software application) or a supplier (system integrator that develop an application to integrate two systems and let it available on the marketplace) at the same time. In the following table the platform stakeholders are categorized following the proposed taxonomy (Table I).

TABLE I. STAKEHOLDERS CATEGORIZATION

Type of Stakeholder	Automation ecosystem stakeholder
Customer	Plant owners; system integrators; equipment/machine developers; component suppliers
Developer / Manufacturers	Application developers; system integrators; equipment machine developers; component suppliers
Service provider	Service providers

Each subject presented in the section above creates a value/monetary flow that interests the marketplace and enables it to be economically profitable. In particular, since the marketplace is the matchmaker among subjects that offer a product/service and subject that require it, two main revenue models are considered: (i) % fee on product/service transactions; (i) fixed hosting fee for product/service hosted on the marketplace.

IV. CONCLUSIONS

The objective of the described solution is to become the centralized platform supporting the hosting of CPS and mechatronic products/services related to IEC61499 product lines. In order to meet the requirements for the deployment of the DAEDALUS ecosystem, the marketplace requires a set of rules and procedures to manage the transactions among the different stakeholders. If the marketplace is the technological infrastructure supporting the exchange of value (products, money, services) among platforms stakeholders, the architecture underpinning it provides the logical constructs enabling the deployment of rules running ecosystems exchanges.

The proposed platform is able to widely manage CPSs in their multifaceted sense (HW, SW, Digital Twin), reaching different (even complementary) customers and offering new opportunities to developers in terms of possibility to create own(ed) control applications and of exploiting validation services thanks to the hosted digital twin.

The infrastructure developed so far is the first step to achieve the challenge of developing a platform able to foster the creation and deployment of more efficient, flexible and orchestrated production systems easy to be integrated, monitored and updated. Next steps to be carried out in order to create a digital platform meeting not only the needs of the developers, but also the needs of the current industrial markets (customers) are envisaged on (i) the creation of specific mechanisms and procedures, software interfaces, and incentivizing system, all supporting the large adoption of the platform, and (ii) the extension of the platform with value added services for customers (e.g. performances assessment of the machines, management of manufacturing systems, manufacturing data elaboration for predictive maintenance forecasting).

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