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IEC-61499 Distributed Automation for the Next Generation of Manufacturing Systems

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Global competition in the manufacturing sector is becoming fiercer and fiercer, with fast evolving requirements that must now take much more into account: rising product variety; product individualization; volatile markets; increasing relevance of value networks; shortening product life cycles. To fulfil these increasingly complex requirements, companies have to invest on new technological solutions and to focus the efforts on the conception of new automation platforms that could grant to the shopfloor systems the flexibility and re-configurability required to optimize their manufacturing processes, whether they are continuous, discrete or a combination of both.

Daedalus is conceived to enable the full exploitation of the CPS' virtualized intelligence concept, through the adoption of a completely distributed automation platform based on IEC-61499 standard,

fostering the creation of a digital ecosystem that could go beyond the current limits of manufacturing control systems and propose an ever-growing market of innovative solutions for the design, engineering, production and maintenance of plants' automation.

4.1 Introduction

European leadership and excellence in manufacturing are being significantly threatened by the huge economic crisis that hit the Western countries over the last years. More sustainable and efficient production systems, able to keep pace with the market evolution, are fundamental in the recovery plan aimed at innovating the European competitive landscape. An essential ingredient for a winning innovation path is a more aware and widespread use of ICT in manufacturing-related processes.

In fact, the rapid advances in ubiquitous computational power, coupled with the opportunities of de-localizing into the Cloud parts of an ICT framework, have the potential to give rise to a new generation of service-based industrial automation systems, whose local intelligence (for real-time management and orchestration of manufacturing tasks) can be dynamically linked to runtime functionalities residing in-Cloud (an ecosystem where those functionalities can be developed and sold). Improving the already existing and implemented IEC-61499 standard, these new "Cyber Physical Systems" will adopt an open and fully interoperable automation language (dissipating the borders between the physical shop floors and the cyber-world), to enable their seamless interaction and orchestration, while still allowing proprietary development for their embedded mechanisms.

These CPS based on real-time distributed intelligence, enhanced by functional extensions into the Cloud, will lead to a new information-driven automation infrastructure, where the traditional hierarchical view of a factory functional architecture is complemented by a direct access to the on-board services (non-real-time) exposed by the Cyber-Physical manufacturing system, composed in complex orchestrated behaviours. As a consequence, the current classical approach to the Automation Pyramid (Figure 4.1) has been recently addressed several times (Manufacture, ICT 2013 and ICT 2014 conference, etc.) and deemed by RTD experts and industrial key players to be inadequate to cope with current manufacturing trends and in need to evolve.

In the European initiative Daedalus, financed under the Horizon 2020 research programme, it has been acknowledged deeply that CPS intrinsic existence defies the concept of rigid hierarchical levels, being each CPS capable of complex functions across all layers. An updated version of the pyramid representation is therefore adopted (Figure 4.2), where CPS are hierarchically orchestrated in real time (within the shop floor) through the IEC-61499 automation language, to achieve complex and optimized behaviours (impossible to other current technologies), while still being singularly and directly

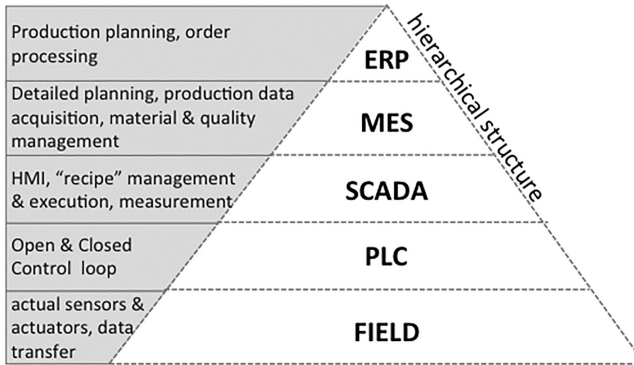


Figure 4.1 Classical automation pyramid representation.

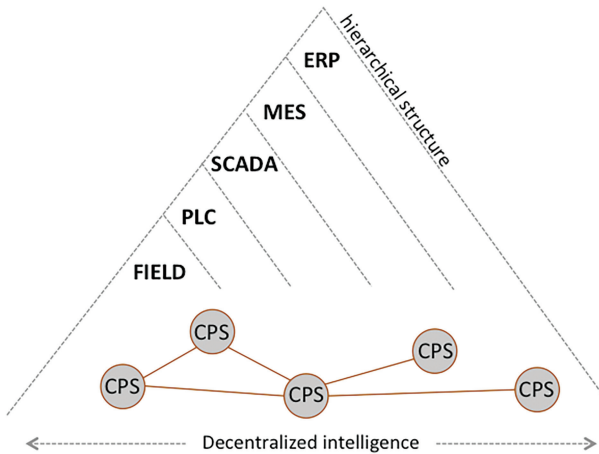


Figure 4.2 Daedalus fully accepts the concept of vertically integrated automation pyramid introduced by the PATHFINDER [1] road-mapping initiative and further developed with the Horizon 2020 Maya project [6].

accessible, at runtime, by whatever elements of the Factory ICT infrastructure that wants to leverage on their internal functionalities (and have the privileges to do that).

This innovative approach to the way of conceiving automated intelligence within a Factory – across the boundaries of its physically separated functional areas thanks to the constant and bidirectional connection to the cyber world – will be the enabler for a revolutionary paradigm shift within the market of industrial automation. The technological platform of Daedalus will become in fact also Economic Platform of a completely new multi-sided ecosystem, where the creation of added-value products and services by device producers, machine builders, systems integrators and application developers will go beyond the current limits of manufacturing control systems and propose an ever-growing market of innovative solutions for the design, engineering, production and maintenance of plants' automation (see also Chapter 13 of this book).

4.2 Transition towards the Digital Manufacturing Paradigm: A Need of the Market

Current worldwide landscape is seeing continuously growing value creation from digitization, with digital technologies increasingly playing the central role in value creation for the entire economy. More and more types of product are seeing a progressive transition to the “digital inside” model, where innovation is mostly related to the extension of the product-model to the service-model, through a deeper integration of digital representations. This means, in concrete terms, that even in very “classical” domains, the dissipation of borders between what is a product and what are the services that it enables is fostering a widespread “Business Model Innovation” need.

Looking at how global competition in the manufacturing sector is becoming fiercer and fiercer, with fast evolving requirements that must now take into account several concurrent factors, it is clear that European Manufacturing Companies have to focus the efforts on new automation solutions that could grant to the shop floor systems the flexibility and reconfigurability required to optimize their manufacturing processes (Figure 4.3).

To realize such a vision, current technological constraints must be surpassed through research and development activities focusing on the following topics:

- interoperability of data/information (versus compatibility) and robustness;

Evolving requirements of the manufacturing sectors:

- Rising product variety
- Increasing relevance of value networks
- Shortening product life cycles
- Quick variation of demand
- Request for high quality and customized products

Needs of new automation solutions to enable:

- *Flexibility and re-configurability*
- *Increased production performance*
- *Reduced energy consumption*
- *Better environmental footprint*



Figure 4.3 The industrial “needs” for a transition towards a digital manufacturing paradigm.

- integration of different temporal-decision scale data (real-time, near-time, anytime) and multiple data sources;
- integration of the real and the virtual data-information towards a predictive model for manufacturing; real-time data collection, analysis, decision, enforcement;
- optimization in complex system of systems infrastructures;
- seamless data integration across the process value chain;
- standardization and interoperability of manufacturing assets components, subsystems and services.

Within this context, the future of Europe’s industry must be digital, as clearly highlighted by Commissioner Oettinger EU-wide strategy [2] to “ensure that all industrial sectors make the best use of new technologies and manage their transition towards higher value digitised products and processes” through the “Leadership in next generation open and interoperable digital platforms”, opening incredible opportunities for high growth of vertical markets, especially for currently “non-digital” industries (Figure 4.4).

The core motivation for Daedalus was therefore born by the awareness that purely technological advancements in themselves are not enough to satisfy the need of innovation of the industrial automation market. New methodologies for the sector’s main stakeholders to solve the new manufacturing needs of end-users must be conceived and supported by the creation of a technological and economic ecosystem built on top of a multi-sided platform.

In developing this concept, Daedalus takes into account a certain number of fundamental “non-functional” requirements:

- CPS-like interoperable devices must be “released” on the market together with their digital counterpart, both in terms of behavioural

Commissioner Oettinger, Hannover Fair on 14/04/2015

- Europe's future is digital
- Digitising European Industry: proposal of four key lines of action
- Focus actions on digital transformation of ALL industry
- Complementing our efforts on a Digital Single Market and on broadband investment

"[We need] to ensure that all industrial sectors make the best use of new technologies and manage their transition towards higher value digitized products and processes [through] the Leadership in next generation open and interoperable digital platforms"

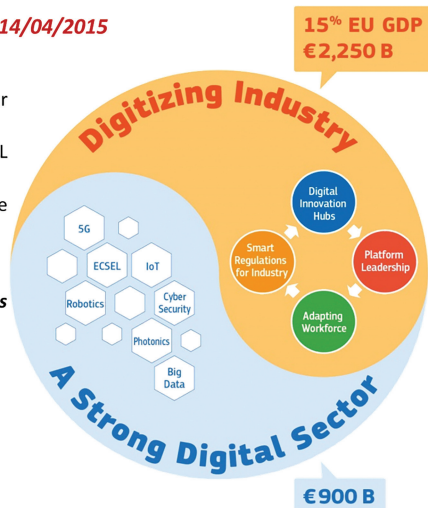


Figure 4.4 Commissioner Oettinger agenda for digitalizing manufacturing in Europe.

models and with the software “apps” that allows their simple integration and orchestration in complex system-of-systems architectures;

- The development of coordination (orchestration) intelligence by system integrators, machine builders or plant integrators (more in general, by aggregators of CPS) should rely on existing libraries of basic functions, developed and provided in an easy-to-access way by experts of specific algorithmic domains;
- Systemic performance improvement at automation level should rely on well-maintained SDKs that mask the complexity of behind-the-scenes optimization approaches;
- Large-scale adoption of simulation as a tool to accelerate development and deployment of complex automation solutions should be obtained by shifting the implementation effort of models to device/system producers;

This translates into an explicit involvement of all main stakeholders of the automation development domain, brought together in a multi-sided market. Such “Automation Ecosystem” must rely on a technological platform that, leveraging on standardization and interoperability, can mask the complexity of interconnecting these Complementors.

4.3 Reasons for a New Engineering Paradigm in Automation

The core conceptual idea launched at European level by the German “Industrie 4.0” initiative is that embedding intelligence into computational systems distributed throughout the factory should enable vertical networking with business process at management level, and horizontal connection among dispersed value networks.

The RAMI 4.0 framework has been therefore developed to highlight this new degree of integration between different aspects of the manufacturing domain, which does not exist only within the usual hierarchy of automation (functional layers) but also across life cycle and aggregation levels (Figure 4.5). The core issue (tackled by Daedalus), which is not apparent enough in this framework, is that the evolution of the Hierarchy Levels, those that characterize the progressive aggregation of physical systems into more complex one, is currently limited by a technological gap between the shop floor and the office floor automation.

In fact, two specific limits hinder the transition towards the next step of the shop floor automation:

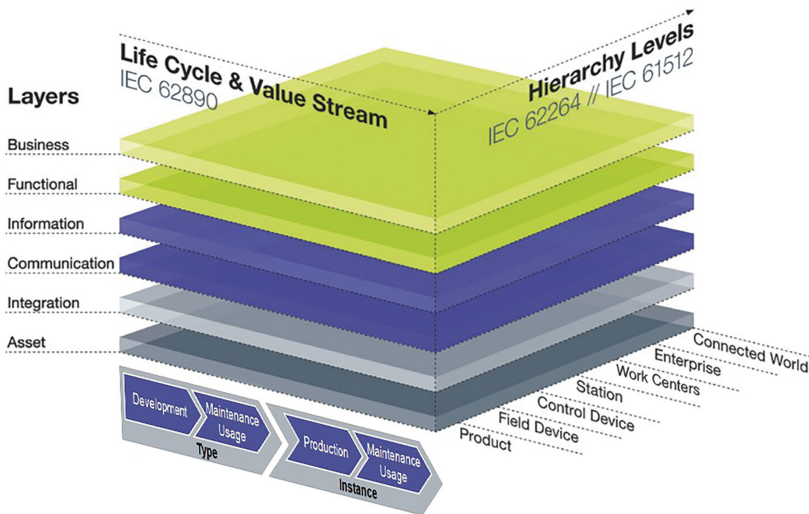


Figure 4.5 RAMI 4.0 framework to support vertical and horizontal integration between different functional elements of the factory of the future.

- Current PLC technology, which dominates the deployment of industrial automation applications, is a legacy of the 1980s, unsuited for sustaining complex “system of intelligent systems” functional architectures;
- Automation languages of the IEC-61131 standard, basis of the aforementioned PLCs, are antiquated from a software engineering point of view; additionally, they have been implemented by each vendor through specific “dialects” that prevent real interoperability.

In technological terms, this has a very specific impact: while products of the automation domain are still completely based on an engineering approach built over the concept of a time cycle (and, consequently, its programming languages), the ICT domain has been working for decades through object orientation and, most importantly, event-based programming. Trying to bring together these two worlds, to guarantee the new levels of integration envisioned by Industry 4.0, is going to be practically impossible if nothing changes in the way industrial automation is conceived and then deployed.

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. As explained previously, distributed automation is considered the needed innovation step; however, 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, as it was conceived for centralized ones. This device-centric and monolithic engineering approach is not well apt for regular changes of the executed control applications, while the multiple engineering tools required for adapting them greatly increases the engineering time, because the majority of vendors implements specific extensions or only partial support of IEC 61131-3.

The IEC took this into account for the development of the IEC 61499 architecture in order to support such new features of next-generation industrial automation systems as distribution and reconfiguration [3], offering modern platform-independent approach to system design, similar to the Model-Driven Architecture [4]. The MDA approach has greatly improved flexibility and efficiency of the development process for embedded systems [5] on account of re-using elements of the solutions, described in high-level languages. We can expect similar benefits from IEC 61499 for industrial automation that MDA brought to software engineering and embedded system development.

The solution is therefore to propose a technological foundation to CPS that could be used to overstep these constraints and consequently enable

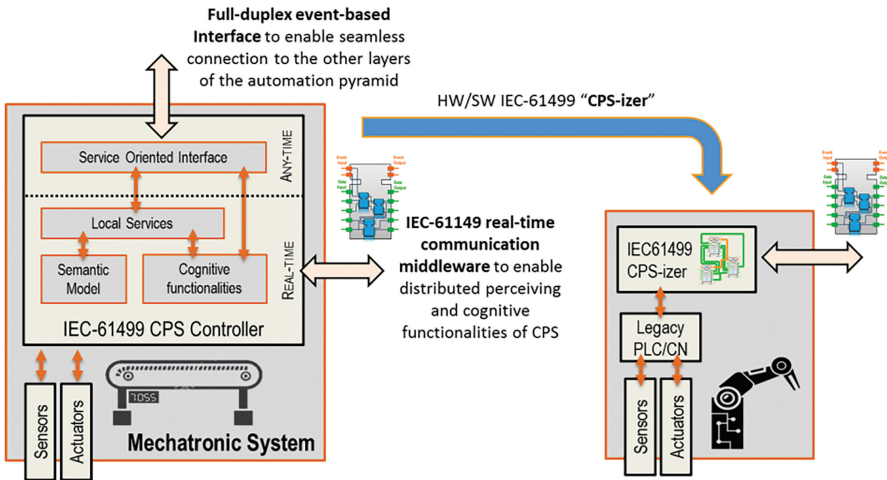


Figure 4.6 Qualitative representation of the functional model for an automation CPS based on IEC-61499 technologies; concept of “CPS-izer”.

the additional functionalities needed by the Automation Digital Platform envisioned by the project. By exploiting the already existing features of the IEC-61499 international standard for distributed automation, the idea is to propose a functional model for CPS that blends coherently real-time coordination of its automation tasks with the “anytime” provision of services to other elements of the automation pyramid (Figure 4.6).

This extension of the IEC-61499 functionalities adopts the openness and interoperability of implementation that the standard proposes, guaranteeing that CPS developed independently will be able to communicate and be orchestrated. But it is not just a matter of interoperable communication between CPS at shop floor level; transition towards an effective digitalization requires other composing elements:

- The real-time automation logic of a CPS must be programmed under an object-oriented paradigm and taking into account the transition from the time-based approach of the low-level control and the event-based needs of a service-oriented paradigm;
- The controller of a CPS must also contain a high-level semantic description of the behavioural models of the system it governs, mapping the automation tasks on top of it; this is needed to allow external modules (in the digital domain) to be capable of reading the raw data generated at shop floor level with the appropriate level of semantic context;

Distributed and progressive elaboration of huge amount (Big) of Data

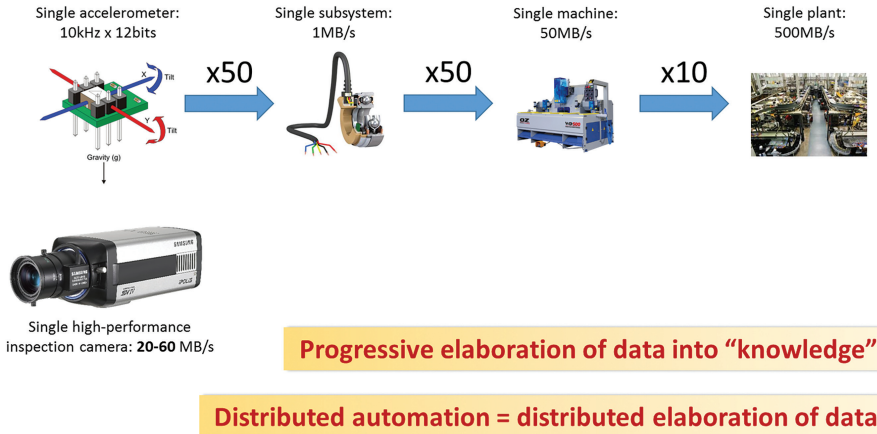


Figure 4.7 The need for local cognitive functionalities is due to the requirements of Big Data elaboration.

- A certain degree of cognitive functionalities must be programmed directly within the CPS, to guarantee that elaboration and modelling of data is done near to the sources of such data (Figure 4.7);

Finally, the “exposition” of services to the digital domain must be conceived by the automation engineer coherently and concurrently to the design of the internal automation tasks, enabling a secure interaction between internal (real-time) automation tasks and “external” requests for asynchronous functionalities.

This notwithstanding, the project understands and accepts the need of CPS vendors (developers) to protect their IP and/or continue using proprietary engineering technologies: the proposed approach supports different levels of “protection” to the inner working mechanism of a system, from a fully IEC61499-compliant but closed (= not accessible by users) implementation, to the “wrapping” of legacy PLCs.

Figure 4.8 therefore shows how the concept of an IEC-61499 CPS (networked in real time with similar systems, compliant with the standard) is only an enabler for a much more complex shopfloor automation, where horizontal integration with other platforms (eventually still in real time) is guaranteed by support to an extensive set of communication protocols and middleware (such as OPC-UA and DDS), while vertical integration through a service-oriented

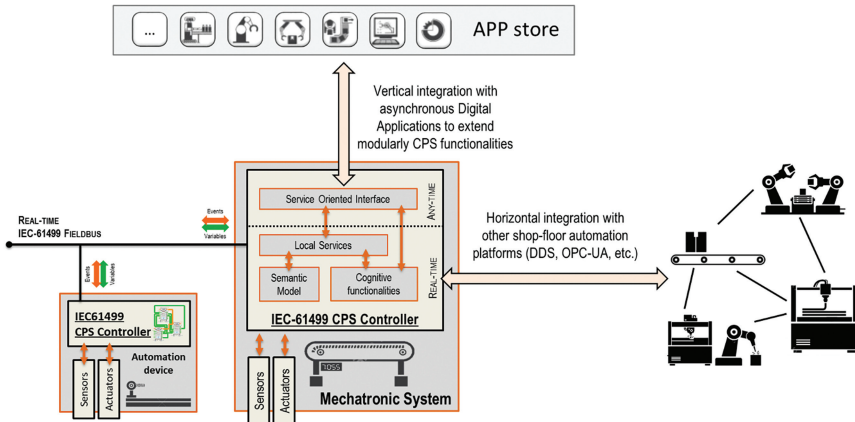


Figure 4.8 Framing of an IEC-61499 CPS within a complex shopfloor.

approach enables the extension of automation functionalities into the digital domain, where the concept of an APP store can greatly facilitate diffusion at market level of this approach.

4.3.1 Distribution of Intelligence is Useless without Appropriate Orchestration Mechanisms

Providing automation devices as IEC61499-compliant CPS is just the enabler for the cornerstone of the project. In fact, the real complexity of future shop floors (and, thus, the opportunities for new manufacturing paradigms) resides in the possibility to develop easily the multi-level orchestration intelligence needed to coordinate the behaviour of all the CPS composing a shop floor.

In fact, the paradigm of decentralization of computing power into smaller devices cannot be deployed only by solving issues about communication about them. Previous attempts to bring the concepts of service orientation into the automation domain has failed when facing the “servers-only issue”: even if an intelligent systems is programmed to “expose” its functionalities as services to be invoked (a “server”, using the vocabulary of SoA), the moment we have several of these servers, the problem that remains is who is going to coordinate those services in an orchestrated way (the “client”) and, most importantly, in which programming language should such a client be designed.

The adoption of IEC-61499 presents automatically the solution to this issue, with an industry-ready approach (validated in several production

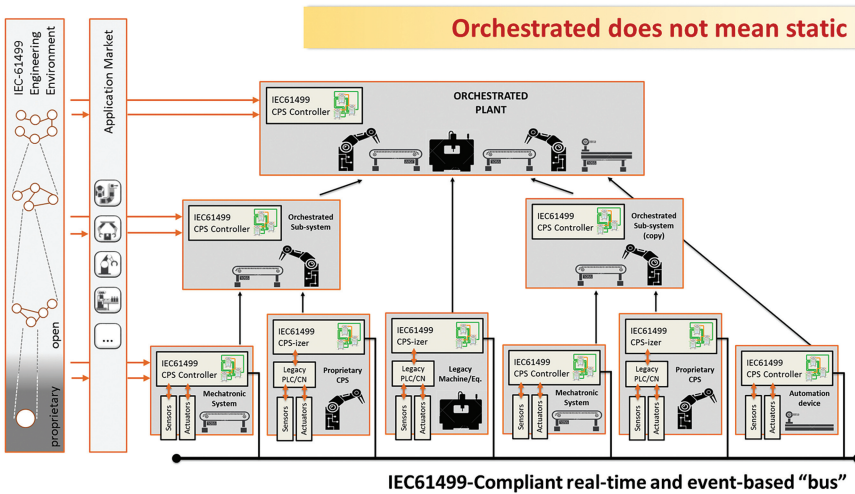


Figure 4.9 Hierarchical aggregation of CPS orchestrated to behave coherently.

environments) that already satisfies the major needs for engineering complex orchestrating applications: interoperability between devices, real-time communication between distributed systems, hardware abstraction, automatic management of low-level variable binding between CPS, a modern development language (and environment), etc. This set of functionalities just needs to be “completed” with additional ones that will make it the undisputed standard at European level.

Figure 4.9 therefore shows how a real “hierarchy” of CPS can be imagined in the shop floor of future factories, where the physical aggregation of equipment and devices to generate more complex systems (typical of the mechatronic approach) must be equally supported by a progressive orchestration of their behaviour, accepting the so-called “Automation Object Orientation” (A-OO, see also Section 4.5 for details) and taking into account that each subsystem may exist with its own controller and internally developed control logics.

The strength of this approach, that is already supported in all its basic and fundamental functionalities by the IEC-61499 standard and programming language, is highlighted in Figure 4.10.

A single CPS, independently from being a basic one or obtained through aggregation of others, can be seen internally (from the perspective of the developer of that CPS) as an intelligent system, which must be programmed

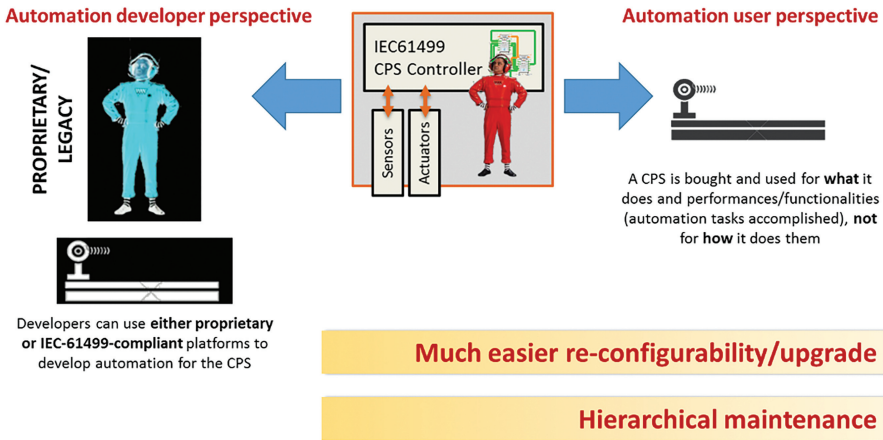


Figure 4.10 Progressive encapsulation of behaviour in common interfaces.

(eventually in proprietary technologies) to exhibit a certain behaviour and expose it over an IEC-61499 interface. On the other hand, seen from outside, the CPS will be a “black box” guaranteeing certain functionalities. This simplifies greatly both the activities of re-configurability and upgrade, and the progressive hiding of maintenance-related details.

Thanks to this unique and innovative approach, new automation systems will be capable of providing simple-to-deploy aggregation of already existing CPS, each one with its own on-board intelligence, to compose articulated “Systems of Cyber-Physical Systems” that, for the final user, will be nothing more than “bigger” CPS, exhibiting concerted behaviours that will mask their internal working mechanisms based on the design decision of the CPS provider.

The adoption of IEC-61499 provides also another opportunity, which is enabled by its natural object orientation (not only at software level but also in dealing with hardware topology through an appropriate abstraction layer): highly increase re-usability of code and applications.

Figure 4.11 shows how the development and IP generation value chain would be applied in the case of high code re-usability enabled by the usage of IEC-61499, where software components of increasing complexity (and aggregation of functionalities) would be progressively employed by different users of the automation domain (further explored in Chapter 13 in its large-scale consequences on the market).

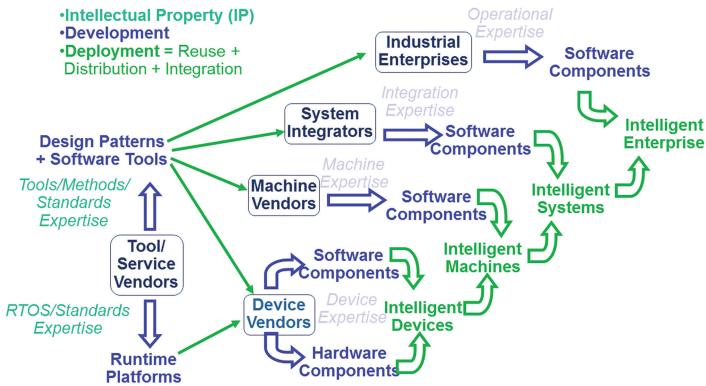


Figure 4.11 IEC-61499 CPS Development, the IP Value-Add Chain.

4.3.2 Defiance of Rigid Hierarchical Levels towards the Full Virtualization of the Automation Pyramid

While the design of orchestrating intelligence supported by IEC-61499 allows the conception of complex aggregated system of systems with advanced behaviour, the CPS functional model (at multiple levels) and the corresponding direct access to non-real-time “services” enables the complete restructuring of the concepts of a factory automation pyramid.

New levels of vertical and horizontal integration can be envisioned thanks to the peculiar service-oriented approach proposed by Daedalus. In fact, current MES and ERP can extend their scopes of application towards the shop-floor by being capable of directly accessing the information flows and elaboration functionalities of the automation CPS; moreover, non-real-time and bidirectional exchange of information can exist between devices even if they are not explicitly orchestrated, such as among products and manufacturing equipment, or between systems of different departments (across the production value chain).

Figure 4.12 proposes a different vision of the factory, extending the point of view outside of the shopfloor and into the so-called “digital” domain, where all the ICT tools of a company exists, from the MES up to the ERP. Hiding temporarily the hierarchy of CPS at shopfloor level shown before (for ease of readability), the picture shows how each IEC-61499 CPS of Daedalus, based on the functional model of Figure 4.6, can connect directly and independently from the other to any “digital module” allowed to do that from a security perspective. This means in practice that:

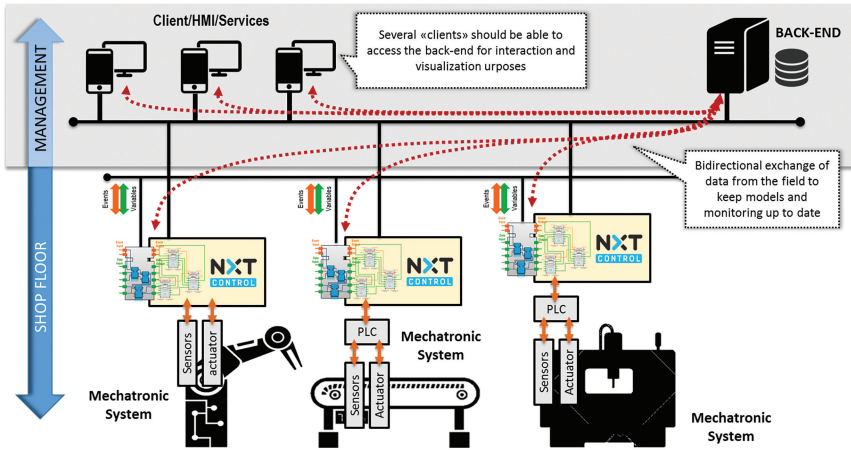


Figure 4.12 Direct and distributed connection between the digital domain and the Daedalus' CPS.

- Asynchronous connections can be established and maintained between a specific CPS and whatever ICT module has the privileges to do so, for instance, for extensive data gathering with semantic description attached; the level of access (within the shopfloor hierarchy of aggregation) is limited only by the granularity enabled by automation developers;
- Each CPS can be programmed to “expose” only the connections and functionalities that its automation developer deems appropriate, increasing at design level the security of the overall connection (apart from specific cyber-security mechanisms);
- Real-time automation functionalities governing the behaviour of the system can be “augmented” by asynchronous access to digital modules conceived to offer specific tools to the automation developer, exploiting, for instance, the higher computational power of a local or cloud server.

As an explicit consequence, the “Industrie 4.0”-envisioned bridging between the execution of the lowest-level manufacturing operations on the shop floor and the highest-level decision making of the top management of a factory is automatically obtained.

4.4 IEC-61499 Approach to Cyber-Physical Systems

4.4.1 IEC-61499 runtime

Based on an overall vision of CPS introduced in Daedalus (see Figure 4.13), an IEC61499 runtime enables the 61499-execution model running on a given OS and hardware platform, for example, the Linux Debian OS running on an ARM cortex platform. The runtime includes an event scheduler module responsible for scheduling the execution of algorithms; a resource management module to handle the creation, deletion, and life cycles of managed function blocks in a deployed application and modules to provide timer, memory, logging, IO access and communication services. The combination of hardware, OS services and the IEC 61499 runtime are collectively known as a device in the 61499 context, and a generic architecture for such a device is illustrated in Figure 4.14.

A control application is developed using an IEC-61499 compliant Engineering tool and then deployed to the device where, when necessary, it utilizes different communication protocols and OS services to interact with other CPS and the physical world (e.g., IO access). The IEC 61499 runtime can be extended to support different communication stacks, field buses and OS service and they are to be encapsulated as SIFB function blocks where

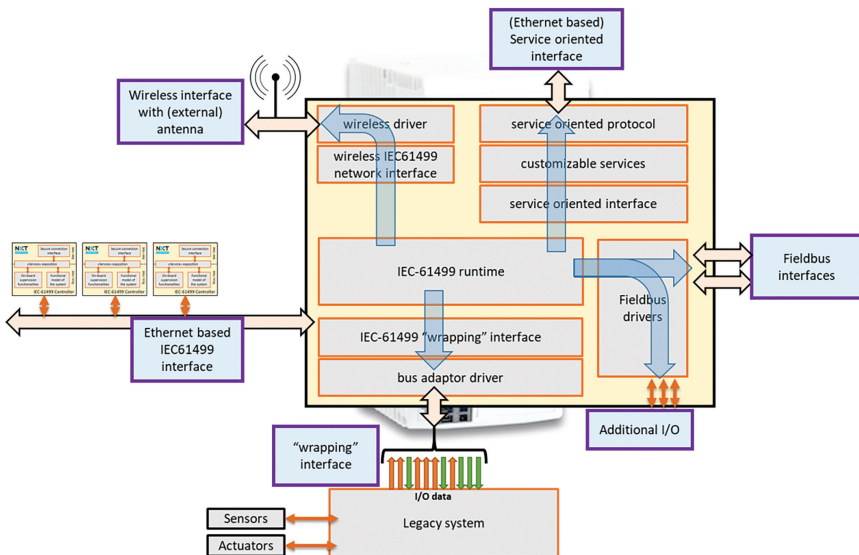


Figure 4.13 Qualitative functional model of an automation CPS based on IEC-61499.

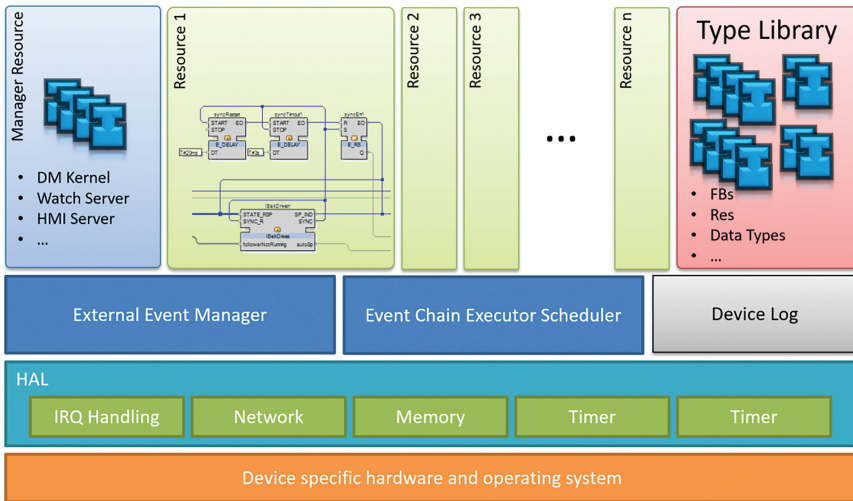


Figure 4.14 IEC 61499 runtime architecture.

the control application can access their services by making event and data connections to them. In this way, the application designer does not require any knowledge about the technical details how the communication will be established. For the platform to be widely applicable, it also needs the ability to communicate with other wireless CPS devices (see Section 4.5).

To enable faster, easier and less error-prone configuration of a network of CPSs in a dynamic changeable network topology, in Daedalus, auto-discovery and self-declaration have been added to the IEC61499 Runtime. To allow this, each device must be capable of creating semantic description of its own interface and functional automation capabilities, making its existence on the network (presence) known to other devices by advertising its entrance and leaving of the network and make necessary exchange of information in standardized, unambiguous syntax and semantics.

The first step is to develop a semantic meta-model for describing the functionalities provided by the CPS. The model must describe the physical interface of the device (parameters) and logical interface to access the automation capabilities it provides. Once the model has been automatically created, it can be exchanged with other CPS in predefined, extensible .xml format.

For the CPS to easily adapt to the dynamic network topology (imagine wireless CPS devices on a mobile platform), where CPS or SoA entities may

join and leave local network at will, the auto-discovery must be based on a zero-configuration (zeroconf) technology, where there is no need to manually reconfigure the network layout or a need for a centralized DNS server, where it becomes a single point of failure. A CPS device participating in a zeroconf network will be automatically assigned with address and hostnames, making low-level network communication possible immediately after a device joins a network. Multicast DNS, a subset of the zeroconf technology, will further allow CPS to subscribe and be automatically notified of changes to the layout of the network.

To support the exchange of semantic information used for identification of other CPS's capabilities in the network, a new communication protocol based on XMPP has been chosen to be included in the IEC 61499 runtime. XMPP is chosen to leverage on mature standards that will encourage a broader acceptance of the solution implemented as well as its intrinsic nature of being extensible via its XEP protocol.

4.4.2 Functional Interfaces

4.4.2.1 IEC-61499 interface

The IEC-61499 interface enables the CPS to connect to a network of IEC-61499-based controllers leveraging a communication profile compliant with the IEC-61499 standard and enabling, as a consequence, a unified and globally recognized communication means with a network of automation devices.

This interface is mainly dedicated to the exchange of real-time data among the CPSs participating to the same IEC-61499 distributed control application, but it is also exploited by other systems to interact with a CPS to accomplish to specific tasks, as for example:

- to configure the IEC-61499 runtime;
- to deploy the IEC-61499 code in the CPS;
- to monitor and debug the IEC-61499 control application.

The IEC-61499 interface is also the interface that is going to host a strong real-time synchronization mechanisms.

From a hardware perspective, the IEC-61499 interface can be implemented both as a wired Ethernet interface, allowing wired and strong reliable connections, and as a wireless interface, providing flexibility in the implementation of a communication network. It is relevant to highlight, however, that the wireless connectivity will pose some limits in the performance

that can be expected for the coordination of the distributed CPS in that network.

4.4.2.2 Wireless interface

The Wireless interface of DAEDALUS' CPS is mainly dedicated to the interfacing with remote devices based on dedicated communication protocols, for application-specific tasks. When the considered task follows in the context of connectivity among IEC-61499 nodes, this interface can partially overlap in terms of functionalities the IEC-61499 interface (in the wireless version). However, while the IEC-61499 interface is designed to be a general communication interface for cooperation of distributed control devices over an IP-based network, the Wireless interface is specialized to support specific communication links. Some examples of specific communication channels for which the Wireless interface would be appropriate are:

- Point-to-point bus communication over a specific wireless technology (different from 802.11a,b,g,n) between two CPSs to support IEC-61499 connectivity;
- Connection to remote device for mono-/bi-directional exchange of data, for example:
 - to a remote I/O module;
 - to a DAEDALUS CPS behaving as a supervisor node;
 - to a third-party technology gateway.

To enable an effective approach, which can make easier to extend in future this to support additional wireless communication technologies, this interface is structured on a dual layer:

- a hardware abstraction layer, which provides the mechanisms to leverage the Wireless interface within an IEC-61499 application, and that hides the details of the communication technology adopted underneath;
- a technology-specific driver, which is leveraged by the abstraction layer to map the expected functionalities over the specific features offered by the selected communication protocol.

4.4.2.3 Wrapping interface

The Wrapping interface constitutes the enabler for an IEC-61499-based controller to operate as a CPS-izer. This interface has to enable the communication with a “legacy” controller through a communication channel not based on the IEC-61499 protocol.

While from the communication protocol perspective, we can foresee different implementations of this interface based on the specific protocol adopted by the CPS to connect to a non-IEC61499-based controller. The main characteristic of this interface is to present a well-defined mechanism to enable interaction with third-party control applications.

Through this interface, it will be possible to enable the cooperation between the event-based approach of a DAEDALUS' CPS with the scan-based mechanism adopted by classic controllers. This enables us to consider the CPS as a wrapper that extends the capabilities of the legacy controller with the IEC-61499 features.

4.4.2.4 Service-oriented interface

The service-oriented interface of a DAEDALUS CPS is fully integrated in the IEC 61499 runtime platform and conceived to enable a dynamic interaction among the CPSs and between the CPSs and the higher automation layers. By means of that interface, a CPS will be able to connect to other systems at the shop floor or at the supervisory/management levels for acquisition of data reflecting the current state of the manufacturing process and therefore extending its perceiving capabilities over the limits of its directly connected sensors.

The service-oriented interface enables a unified methodology of interaction among the intelligent units of the manufacturing plant and, at the same time, the possibility for an orchestrating unit at supervisory/management level to interact directly with the network of cyber-devices and coordinate their action, without requiring compliancy with the IEC 61499.

A CPS exposes through its service-oriented interface a set of functionalities that are exploited by an orchestrating intelligence to reconstruct a better understanding of the actual condition of the manufacturing process and of the CPS' behaviour and to elaborate more accurate and effective coordination plans, which are then used to instruct appropriately the single automation units.

The service-oriented interface provides a flexible communication mechanism that does not require the specification of all the nodes involved in the communication at design stage, hence making the application easy to scale.

The specification of the service-oriented interface defines (among other aspects):

- The architectural mechanism to integrate the service-oriented interface within an IEC-61499 runtime;

- The protocols supported by the initial implementation of the DAEDALUS platform;
- The set of services implemented as a first prototype of the interface.

4.4.2.5 Fieldbus interface(s)

To enable a DAEDALUS CPS to be applicable to different application scenarios, the CPS should support connectivity toward other automation devices through common fieldbus technologies.

The fieldbus interface(s) can be of different types and the specific implementation will depend on the types of technologies, for which the appropriate driver will be available/implemented, and the application requirements.

The general goal of this interface is to provide I/O communication with other automation devices. Some of the common fieldbus technologies that are planned to be supported are EtherCAT and Modbus TCP/IP.

4.4.2.6 Local I/O interface

The Local I/O interface represents a specific interfacing mechanism toward the I/O modules locally installed in the same HW platform of the CPS.

From a functional point of view, this interface is similar to the Fieldbus interface, but it is specialized to enable the exploitation of the resources characterizing a specific implementation of DAEDALUS CPS: those resources can leverage custom/proprietary communication mechanisms, instead of common standards.

4.5 The “CPS-izer”, a Transitional Path towards Full Adoption of IEC-61499

The technological concept is that of a CPS-izer: a small-footprint (and costs) controller, based on the IEC-61499 technologies of Daedalus, is also capable of interfacing with usual PLCs through standard communication buses (Figure 4.15). This could provide a path for transition towards digital automation to two major families of users:

- End-users will have access to a product that can be easily installed on existing machines and manufacturing systems and, with a limited engineering effort, used to upgrade their plants prolonging functional life;
- Other developers of automation platforms compliant with IEC-61131 will have a temporary solution to make their systems at least partially coherent with the new IEC-61499 standard.

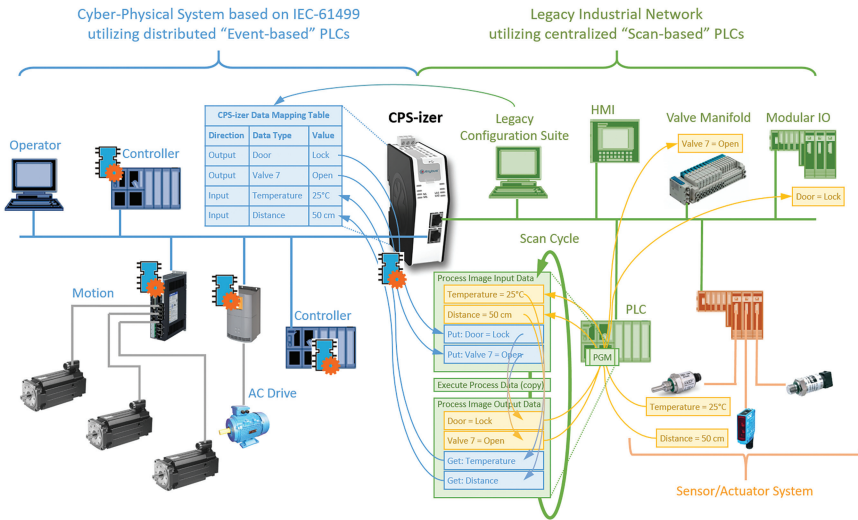


Figure 4.15 IEC 61499 CPS-izer.

Finally, the object-oriented approach that the standard adopts will not be limited a priori to automation algorithms only, but it can be extended to further “dimensions of existence” of the system, guaranteeing two important added values. Behavioural models of CPS (needed for several purposes, such as simulation) will become explicit elements of the device virtual representation (avatar), enabling seamless (= transparent to the end-user) connectivity between the device deployed on field and its models memorized in-Cloud. In addition, synchronization and co-simulation in near-real-time will be automatically achieved as already part of the functional IEC-61499 architecture, with the event-based nature of the standard perfectly suited to deal with the management of Big Data coming from the field.

The CPS-izer follows the same common requirements like for an IEC-61499 Controller device, but deviations of the implementation of the common requirements for the CPS-izer in comparison to an IEC-61499 Controller device are possible. Besides these common requirements, there are other requirements and constraints defined for the CPS-izer. First of all, the CPS-izer needs to provide support for legacy industrial networks.

Legacy industrial networks are characterized by means of their physical and data link layers (e.g., Serial, CAN, Ethernet) and the transport layers up to the application layers depending on the implemented technologies (e.g., Modbus/RTU, PROFIBUS, CANopen, PROFINET).

The CPS-izer supports these legacy industrial networks by means of the adaptation of an interface, which could be implemented by hardware, software or IP-core. The preferred solution for the CPS-izer in Daedalus is the HMS Anybus[®] (see <https://www.anybus.com/products/embedded-index>) embedded product family of various industrial interfaces. The CPS-izer only implements a slave/server/device in terms of the applied industrial networking technology. As a restriction, here the CPS-izer cannot be used as a master/client/controller in any industrial network.

One constraint of this device is that it will only support connectivity to legacy industrial networks but no IO data as signals, neither discrete nor analogue. As for an example, other IO modules connected in the legacy industrial network controlled by a PLC in that system can be used if additional IO signals are needed. Also, no support for IO data like in industrial sensor/actuator system (e.g., AS-Interface, IO-Link) will be provided. Those systems would require a master to be implemented, which is out of scope for the realization of the CPS-izer. If IO data from such systems need to be exchanged with CPS, this shall be realized by using an appropriate master in the legacy industrial network controlled by a PLC in that system. The CPS-izer may have limited resources for IEC 61499 functionalities compared to the IEC 61499 Controller when it comes to the implementation of the runtime system. It must of course implement function block(s) and driver(s)/interface(s) to handle the data transfer to the legacy industrial network connected.

The CPS-izer will map input data and output data between CPS and legacy industrial networks. For this, the CPS-izer will implement some kind of a shared memory (in either physical or logical way) to exchange data. The data mapped to this area will be consistent in common for all inputs and outputs mapped with the legacy industrial network. It may be consistent to a finer granularity depending on the types of devices connected.

Since all legacy industrial networks share the same implementation approach of mapping data, this will be the lowest common denominator of all such systems. So, the CPS-izer will follow this philosophy. Some – but not all – legacy industrial networks provide events like alarms or diagnostic messages. That implementation is always specific to the industrial network, but no generic solution will be available for this. So, the CPS-izer will not support events of the legacy industrial networks.

The configuration of the available input and output data in CPS-izer will be specific to the legacy industrial network it is connected to. The tools and methods typically for such networks are applied. The PLC in that system is responsible to get the input data from CPS-izer and write them to the outputs

of the devices. On the other hand, it will collect the inputs from the devices and put them into the output data of the CPS-izer. The processing of output and input data in the PLC will follow the common approach for a scan cycle as it is implemented in automation industries since decades: read inputs – execute process data – write outputs.

In terms of such PLC systems, the CPS-izer will put output data from the legacy industrial network to the CPS, which is seen there as input. It will get output data from the CPS, which is seen as input in the legacy industrial network. For the CPS-izer, the execution of the process data in the PLC is just a copy function to copy data from the process image input to the process image output.

Some legacy industrial networks like EtherCAT or PROFINET provide real-time capabilities to transport IO data in the ms or even s range of cycle times. This real-time behaviour will not be made transparent to the CPS. The CPS-izer will only guarantee data consistency between CPS and legacy industrial network related to the cycle time running in that network, but it cannot guarantee real-time transport between both systems.

The CPS-izer should be realized in a small industrial-approved plastic housing, which could be easily mounted at a machine or in a cabinet using DIN-rail mechanics. It should require a single 24 V power supply as used in standard industrial automation systems. Furthermore, it should realize a common way to connect to legacy industrial networks by means of front plugs/connectors and indicators.

The CPS-izer should follow requirements for industrial grading like temperature range, shock and vibration, EMC and others for common cabinet mounting. It must adhere to CE compliance.

Harsh industrial requirements like IP67, sealed connectors and housing and higher temperature range are not in the focus of the realization of the CPS-izer.

4.6 Conclusions

This chapter has explored a new generation of functional architecture for industrial automation, centred around the concepts, methodologies and technologies of the IEC-61499 standard but exploiting and extending them for a concrete implementation of what are called “Cyber-Physical Systems”.

The transition to this type of model is not just a matter of installing new devices into a shopfloor, but it requires a real paradigm shift in the way real-time control and automation in manufacturing are engineering, introducing new concepts of design and the corresponding skills.

Daedalus project is developing all the tools to enable such a transition, considering both green-field and brown-field scenarios, accepting that Industry 4.0 full implementation will need a radical change in the way existing PLCs work.

Acknowledgements

This work was achieved within the EU-H2020 project DAEDALUS, which received funding from the European Union's Horizon 2020 research and innovation programme, under grant agreement No 723248.

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