Tema 6:
Implementação de Arquitetura de Máquinas/Agentes Autônomos em cenário de Indústria 4.0

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1. INTRODUÇÃO

Industry 4.0, or *cyber-physical production systems*, is a new concept being gradually adopted by manufacturing enterprises in order to increase their general efficiency and sustainability while coping with the need of highly customized and shorter lifecycles products and emerging product-service systems.

Benefiting from the advances on industrial automation, information and communication technologies (ICTs) and control and management models – shopfloor systems and equipment have turned into much more active entities within the wider, intensively collaborative and smarter production environment that characterizes the Industry 4.0 scenario.

A number of core-systems' design principles have been considered as a must to be supported by manufacturing enterprises when adopting Industry 4.0 architectures, platforms and technologies: interoperability, modularity, virtualization, real-time information, service-orientation, and decentralization/autonomy.

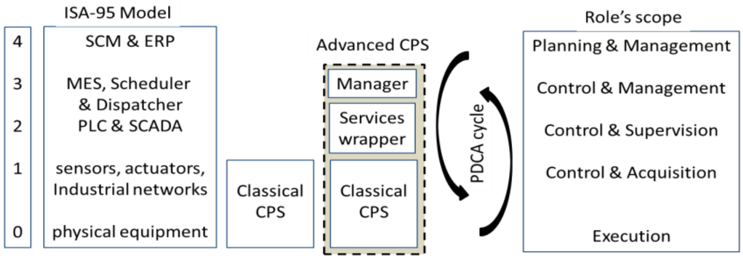
Although much emphasis has been put on the "automation and control" part of the digitalization process of production systems, including on the so-called *cyber-physical systems,* many research works in literature have only proposed theoretical models for that or have provided just general visions on how a machine can indeed act as an smart, active and autonomous element in the shopfloor.

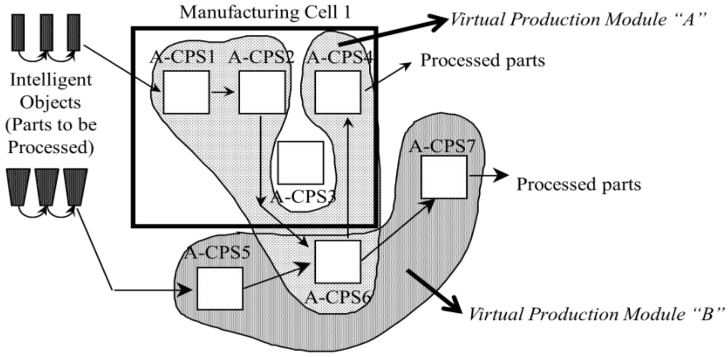
2. ARQUITETURA DE UM A-CPS

Cyber-Physical Systems (CPS) represent the integrated computational and physical capabilities - such as sensing, communication and actuation - to physical world, with feedback loops where physical processes affect computations and vice versa. When immersed in the Industry 4.0 scenario, advanced CPS (A-CPS) architectures should incorporate its design principles, which are: interoperability, modularity, digitalization / virtualization, real-time information, service-orientation, and decentralization / autonomy.

Industry 4.0 scenario is however a target to be reached by companies as they are mostly in the 'Industry 3.0' era yet. Therefore, it is important to also support some "transition aspects" in the architecture so that A-CPS can also work within classical control models and legacy systems.

From the envisaged A-CPS point of view, this means that an industrial equipment is no longer seen 'just' as a passive workstation working under a hierarchical and top down control structure, composed of a machine, its PLC, sensors and actuators, integrated via industrial networks, able to communicate with SCADA systems, and designed to manufacture (predefined) passive parts based on given (predefined) process plans. Instead, it is seen as an autonomous entity immersed in the factory's ecosystem embedded with production management and self-management abilities, including lean manufacturing concerns and eco-awareness. It pro-actively proposes alternative process plans, opportunistically, competing for new orders based on its current and foreseen occupation and self-management goals, making scheduling and dispatching as emerging bottom-up and adaptive plans, or to autonomously refine the initial plan as production goes on and problems take place. It is flexible for dealing with several different 'active' parts - intelligent objects - embedded with *e*-tags, etc., and interacts on-demand with other A-CPSs, manufacturing resources and computing systems (as MES and Cloud) aiming at looking for shop floor partnerships to cope with current order's requirements, both in normal operation and exception handling, leveraging creating temporary virtual production modules over existing layouts. All this works under a *P*lan-*D*o-*C*heck-*A*ct/*A*djust cycle. Figures below show the general architecture and view of the envisaged A-CPS.





In order to respond to the Industry 4.0 requirements, mainly in terms of autonomy, decentralization and modularity, the A-CPS architecture extends the classical CPS's with two additional layers: the *Manager* and *CPS wrapper*. This extension can be seen as a manufacturing connector. This tandem architecture is suitable for this case, allowing logical and physical decoupling of the planning / master / intelligence layer from the control / server / execution layer, but transparently to A-CPS client applications.

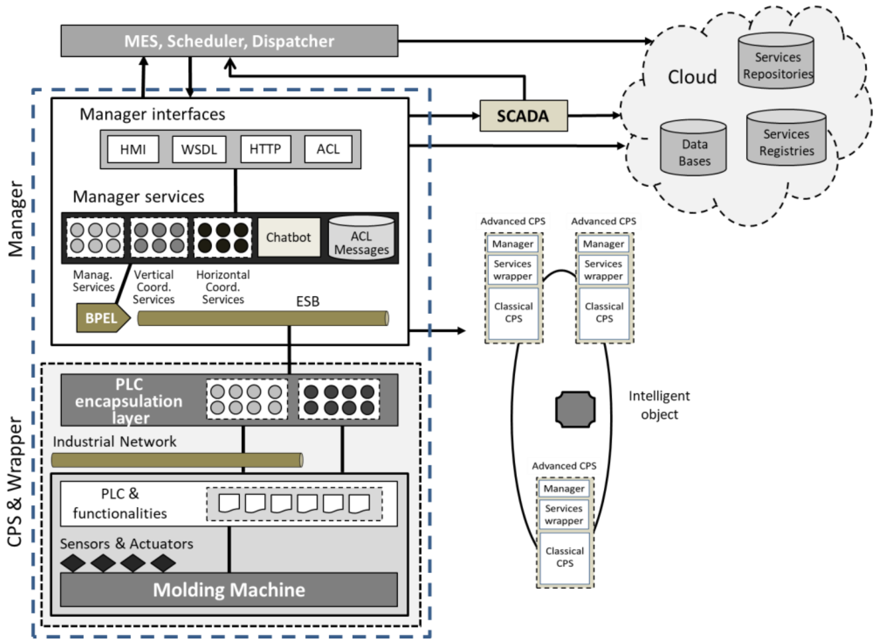


Fig 7. Advanced CPS detailed view and architecture

While the Manager works for satisfying the client applications' needs (e.g. in terms of real-time time information from the moulding machine) and to handle the machine 'agenda' respecting local and global performance goals (for example, to collaborate with other A-CPS, to maximize its local utilization, and to minimize energy consumption as part of a global energy policy), the Server (i.e. the moulding machine) keeps operating accordingly.

The wrapping corresponds to an integration strategy / model and has three fundamental objectives: acting as a layer to hide the heterogeneity and/or complexity of native implementation environments of the provider (the CPS server); providing a more homogeneous and/or standard way to access the server's functionalities from clients hence mitigating interoperability problems; and creating new or aggregated views from the existing server's functionalities to clients.

The view of autonomous, self-evolving, adaptive, scalable collaborative and flexible production entities is not new at all, being quite explored in the 90's mainly in the area of holonic manufacturing systems (HMS). Such systems are composed of elementary entities called *holons*, which can form *holarchies* (e.g. a virtual production module) to attend production requirements. Regarding to the inherent properties of multi-agent systems, agents have been largely used to model and implement HMS or intelligent distributed manufacturing systems. The wrapping of a manufacturing resource (or other system) by agents is usually called as 'agentification'. In summary, the manager layer of a A-CPS acts as an agent, which is a base to support intelligent, distributed and decentralized control.

The Manager 'personalizes' the CPS within the production system, and represents the autonomy and decentralized decision-making properties of the CPS in the Industry 4.0 scenario. In general, it allows: the respective CPS to be 'plugged' into the global control architecture; to 'play' within it when required (as information and service providers and to interact with other A-CPS); and to be 'unplugged' from current production modules (Figure 6).

Depending on the physical organization of the shop floor and existing PLCs, a Manager can represent more than one CPS (for example, a workstation composed of a mould machine equipped with an automated buffer and a robot to feed it).

There is a proper computing interface for each of these 'actors'.

Following the same integration strategy, the PLC functionalities are also wrapped, in the *PLC encapsulation layer*. It can be seen as the PLC's high level "API". This encapsulation can comprise two types of access: the ones that allow a communication with the native PLC functionalities, wrapped as services; and the ones that allow a communication with eventual commercial products deployed on top of PLCs, via their API, to access data from the equipment, usually using the OPC UA standard protocol.

Regarding that several interactions between the A-CPS and the outer environment actually refer to information and actions upon the respective PLC and machine, the Manager's services should provide means to communicate with them. However, the Manager and the CPS are decoupled computing environments, and the involved functionalities are usually implemented in different technologies.

In order to overcome interoperability problems a BPEL (*Business Process Execution Language*) - ESB (*Enterprise Service Bus*) approach can be used. Although the communication between the Manager and the PLC tends to do not involve complex business processes models, a BPEL file can easily comprise the set of required services invocations in a standard way. It can feed the internal ESB, which acts as an interoperable bus binding given services invocations to the involved and heterogeneous wrapped PLC functionalities, considering their local implementation model and technologies.

All services are registered in the Services Registries and stored in the Services Repositories. Many different deployment models can be adopted to support the whole system' architecture, be them totally deployed in a cloud, be them totally deployed in the company's local servers.

3. OBJETIVO

Neste momento esta arquitetura é apenas uma "proposta conceitual".

Assim, no mestrado, o objetivo seria o de refinar o modelo conceitual (incluindo tomar como referências alguns outras propostas do estado da Arte) e Implementar esta arquitetura de avançado sistema ciber-físico no contexto de Indústria 4.0.