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The Holonic Production Unit: An integrated automation architecture

La Unidad Holónica de Producción: Una arquitectura integrada de automatización

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Resumen

El proceso de construcción de sistemas integrados para la automatización, se inicia en los años 70, 80 del siglo XX bajo la propuesta CIM (Computer Integrated Manufacturing). Esta propuesta parte de un enfoque piramidal, donde las funciones de planificación y programación de la producción son dificiles de lograr por la estructura centralizada para estas funciones. El trabajo presenta una propuesta de arquitectura de control descentralizada, donde cada unidad de producción es autónoma, descrita bajo el enfoque holónico dando origen a la Unidad Holónica de Producción. Esto logra que las actividades asociadas a la programación de la producción sean distribuidas, cumpliendo con los objetivos de Industria 4.0 desde las perspectivas de los Sistemas de Producción Ciberfísicos.

Palabras clave: Industria 4.0, Arquitecturas de Integración, Sistemas Ciber-físicos, Sistemas Holónicos, Arquitectura de Referencia Internet Industrial.

Abstract

The process of building integrated systems for automation began in the 70s, 80s of the 20th century under the CIM (Computer Integrated Manufacturing) proposal. This proposal is based on a pyramidal approach, where the planning and scheduling of production functions are difficult to achieve due to the centralized structure for these functions. The work presents a proposal for a decentralized control architecture, where each production unit is autonomous, described under the holonic approach, giving rise to the Holonic Production Unit. This makes the activities associated with the production scheduling are distributed, complying with the objectives of Industry 4.0 beyond the perspectives of Cyber-Physical Production Systems.

Keywords: Industry 4.0, Integration Architectures, Cyber-Physical Systems, Holonic Systems, Industrial Internet Reference Architecture.

1 Introduction

In a production system, a multiplicity of resources are combined that carry out processes following a certain sequence, in order to obtain a product that satisfies a market need. The processes can be of a physical nature where equipment, operators, supplies, energy are combined to carry out extraction, storage, transport, transformation of materials until obtaining a final product (manufacturing processes); logical processes that plan, schedule, coordinate, evaluate the results of physical processes that are distributed over time in order to obtain said final product, as well as processes that help determine production objectives that depend on the interaction of the company with the outside world. Manufacturing processes in industries are being supported by the presence of information technologies throughout all processes, both the core ones and those supporting production, (Cardin et al.2018). The logical processes, responsible for decision-making, perform their tasks using the knowledge of how to do it and the state of the resources, both expressed in models that are interpreted by the logical part (Rajsiri et al. 2010).

The Industry 4.0 (Bartodziej 2017, Oztemel et al. 2020} or cyber-physical production systems (CPPS) approaches, assumes that manufacturing and business processes are fully automated and integrated in order to evolve to the customization of mass-produced products, whose success is guaranteed by the flexibility to establish configurations and reconfigurations online thanks to the intelligence of your processes. This would not be possible without an information technology, communications and operations (ICT \& TO) architecture that supports it. While it is true that this approach is associated with the manufacturing industry, it can be generalized to the continuous process industry, batch and critical infrastructure systems.

The ICT/OT architecture must support the control architecture established for the management of the company's production processes. The first element to establish is the definition how the different processes will interoperate. Several integration and control architectures have been proposed to date for Industry 4.0 (Meissner et al. 2017), and an integration platform for it, which represent an evolution of the first Computer Integrated Manufacturing (CIM) approaches such as CIM-OSA and PERA. A new integration approach for Industry 4.0 is given by Rami 4.0 (Adolphs 2015).

1.1 I4.0 Requirements from CPPS

In (CruzSalazar et al. 2019 , the authors explain that the implementation of Industry 4.0 (I 4.0) must be based on the New Information and Communication Technologies (**NICT**), and its integration must apply the Industrial Internet of Things (**IIoT**) in the processes of manufacturing, as well as the use of other techniques and technologies such as Big Data, autonomous robots, 3D simulation, artificial intelligence, 3D printing, autonomous vehicles, nanomaterials, blockchain, biotechnologies, etc. until the conception of Digital Twins as cognitive models in these intelligent systems.

Currently I4.0 focuses on Cyber Physical Systems (CPS). Most researchers define the origins of CPS as the natural evolution of embedded systems. According to this conception, various embedded devices are networked to detect, monitor and activate physical elements in the real world, which may include connectivity, this being a crucial enabler for future technological developments. When this conception is extrapolated to production systems, Cyber-Physical Production Systems (CPPS) are obtained. The CPPS, Monostori et al. 2016, consist of autonomous and cooperative elements and subsystems that are connected based on context within and across all levels of production, from processes through machines to production and logistics networks. Three main features of CPPS are highlighted here:

- Intelligence (smartness), that is, the elements are capable of acquiring information from their environment and acting autonomously
- Connectivity, that is, the ability to establish and use connections with the other elements of the system, including human beings, for cooperation and collaboration, and with the knowledge and services available on the Internet.
- Responsiveness to internal and external changes.

Monostori2016} proposes the 5C architecture, shown, see Fig. 1, which consists of five levels in a sequential workflow form and illustrates how to build a CPPS. This paper provides examples from the field of monitoring at the process, machine, or system level, as well as a description of the architectural levels. In a CPPS, the smart connection level (Level I) represents physical space, Levels II-IV the ``pure" cyberspace, while the configuration level (Level V) accounts for the feedback from cyberspace to physical space

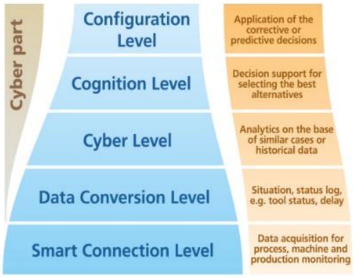


Fig. 1. 5C CPPS Architecture, from (Monostori et al. 2016.

Cardin 2019 defines four aspects to consider in the CPPS in the industry, among them ``The Learning Factory", which demands engineers and technicians trained to work in this environment. In addition, the implementation of such systems requires a near real-time IT architecture connected to a real-time OT architecture that controls the physical system.

Process, product, and equipment models are required to describe, program, monitor, and control the physical system. Glatt et al. 2019 indicates that the flow description models are shown as necessary to carry out the programming activities. CPPS models must describe the behavior of processes at various levels (plant-level execution, supervision) to have an integrated operation of the different CPPS working together to meet production objectives. Those models are digital twins of physical processes and equipment.

The objective of the present work is to describe a decentralized architecture based on the holonic approach (Valckenaers et al. 1997, McFarlane et al. 1995) centered on the intelligent resource, which complies with the CPPS requirements previously exposed. The work presents in the section 2 an ontological proposal for the description of production processes. Different control architectures associated with the automation of production systems are shown in the section 3. The section 4 describes the proposed decentralized architecture for integrated automation that is based on the holonic scheme. Finally, the conclusions of the work are given.

2 Ontologies for Production Systems

For the description of the production process, in the literature there are terms such as: process configuration, product path, product master, product model, which must have the same meaning for all participants in production tasks such as production planning activities, production scheduling, allowing to generate production orders, work orders, dispatches, etc. This amount of concepts should be grouped around a small group of definitions that serve to establish a common semantics in the company. Within the definitions we find: i) *Product, Process, Resource* (**PPR**) (Cutting-Decelle et al. 2007, Pfrommer et al. 2013, Seitz et al. 2021); ii) in the holonic approach are defined as central elements Product, Resource, Order in **PROSA** (VanBrussel et al 1998), this approach mutates to **Arti** *Activity, Resource, Product Model, Product Path* (Valckenaers 2020); iii) Borgo et al. 2007, within holonic systems, define for **Adacor** *Resource, Task, Product, Supervisor*; iv) Järvenpää et al. 2019) proposes MaRCO (Manufacturing Resource Capability Ontology) that uses the concepts of *Resource, Capacity, Product and Process* and their relationships. Additionally, a concept such as Service Oriented Manufacturing (SOM) (Jammes et al. 2005, Tao et al. 2011, Lu et al. 2019, Iarovyi et al. 2015, Zhong et al. 2017) allows the production process to be described as the chain of a set of services that are provided by intelligent resources

For the description of the production process, in this work an evolution of PROSA is proposed as an ontology for the description of the production model where an element of relationship between the resource, the product and the order (process) is the *Activity* and the *supervisor* taking into account that an activity is carried out according to a product model in resources that have certain capacities to execute a production process. The central elements for the description of the production process are i) Product, ii) Resource, iii) Order/Process and iv) Activity, which are described below. The supervisor and the activity are closely related, since the supervisor is the control mechanism that ensures its execution according to the plan.

2.1 Product description

In a traditional way, the *Product* is defined by the information about the physical characteristics of the product, its formula and the associated procedure for its manufacture (Product Master) (Hoffman et al. 1998) and evolves towards a representation of the product life cycle (**PLM** Product Lifecycle Management) (Sudarsan et al. 2005), which supports the management of the business process, and the manufacturing process from the conception of the product to its removal from the shelves. The manufacturing and marketing process corresponds to the stages defined in the conception of the product for its manufacture, including the acquisition of inputs until the delivery of the product to the consumer, where each stage is carried out by specialized units, and the processes are specific according to the resource; two different resources can have different procedures for the same stage. The third key element is the production order, which determines when the production activity will take place. A production ontology appears as a fundamental element to specify, analyze control architectures, which can be focused on the resource, on the product or on the process, but that consider all the elements associated with the decision-making process.

The product description has two aspects: *type* and *instance* as defined by Rami 4.0 (Rojko 2017). As a type it describes the production method and its physical characteristics, and as an instance the real product, which is acquired, produced, stored, sold and has a quality (verification of physical characteristics), an associated cost (monetary and energy) for which has its trace. Fig. 2 shows the definition of the product type, and its relationship with a product instance.

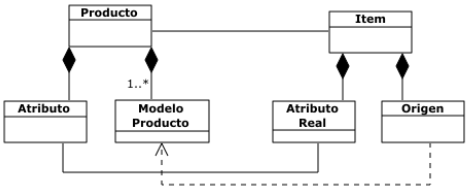


Fig. 2. Product description

2.2 Resource description

The resource is associated with the infrastructure, where production services are performed, whether physical or logical (Xu2012). A resource has capabilities to provide manufacturing services, and these capabilities may be available or committed at a certain time to perform some tasks. See Fig. 3 for the description of the resource. A resource connects with another resource through ports where matter or energy circulates.

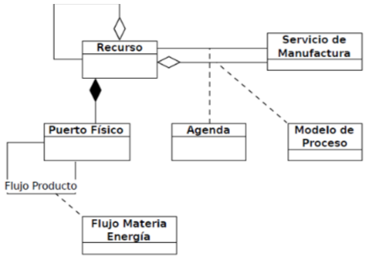


Fig. 3. Product description

Wan et al. 2018) proposes an ontology based on the intelligent resource, which allows to establish reconfigurations to achieve production objectives. The smart resource allows the implementation of the concept of service-oriented manufacturing.

2.3 Process description / Production orders

Obtaining a product is given by a flow of materials associated with a sequence of processes in order to obtain a product. Each process can be made up of threads, and the processes or threads are interdependent on each other.ach production order has a recipe that is determined in advance and that when executed by the resources, a product is obtained.

Zaletelj et al.2018} presents a process-centric ontology and defines a hierarchy of processes that are activity, operation, task, process, plan, work order. The execution of a work order implies the definition of a detailed plan down to the level of activity, which when executed produces a result. The generated plan can be validated by simulation and monitored during its execution to establish its correctness and progress. Saez et al. 2021 indicates that the models must be able to predict the behavior of the process, its consumption, etc. To refine the models, it is necessary to integrate the forecasts made with the values obtained from the plant floor.

The description of the process, shown in Fig. 4, indicates on the left side the process to be executed corresponding to a production order. The Activity shown on the right is what is actually running or was run. The process model is built in the planning phase of the order.

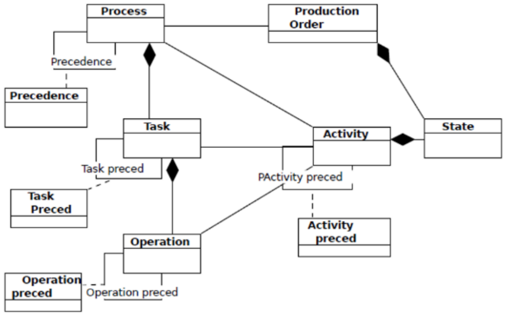


Fig. 4. Process description and its relations

2.4 Relaations among the base class (The Activity relation class)

The dynamics of the organization is established by the classes that specify the relationships between Process (P), Resource (R) and product (P), as shown in Fig. 5. Here the Activity is the central element, it is carried out in a resource, following the method of the respective product whose projection in the process is the result of the relationship (physical -- logical) existing between the services - associated resources to produce the product.

3 Control architectures in process integration

A control architecture defines the various components and their interactions in order to find a physical configuration to satisfy a production order using knowledge and information about production. The *Control Loop* in an intelligent system according to Albus 1991 implies a group of activities such as the monitoring of the process, the existence of models to establish forecasts and determine the current state, and the mechanisms to transmit decisions to the system that you want to control, as shown in Fig. 6.

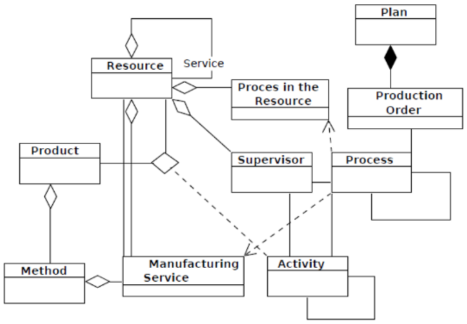


Fig. 5. Abstraction of the relations among Process, Resource, Product

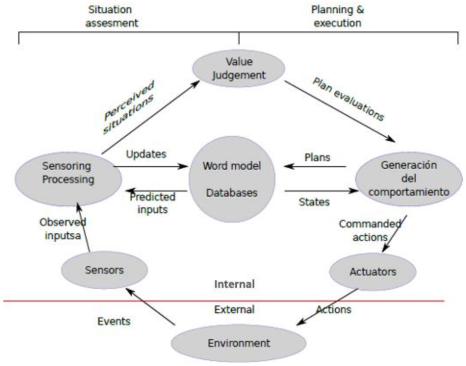


Fig. 6. Intelligence components and its functional relations. Adapted from Albus1991

3.1 Distribution of the functions in a production system

The decisions in the organization are decomposed vertically according to the type of decisions: planning and execution creating a flow of exchange of ``information about the state" and ``decisions", as shown in Fig. 6, which is vertical and horizontal flows of matter, energy and horizontal information transfer between specialized units according to their function, be it physical or logical.

3.1.1 Vertical Distribution of the functions

The operation of the organization is subject to a decision-making structure, it is described by a 5-layer structure similar to ISA-95 model (ISA-952000) introducing considerations of the CPPS (Monostori et al.2016). The layers allow synergy between the different vertical processes. Its functions are defined below:

- Long-term planning that contains the functions of a) Product design and b) Generation of the product model and production methods in addition to the financial economic functions. (Layer 5)
- Planning, with the functions of evaluation of economic viability, incorporation of the requirement to the production plan, interaction with the external world through the generation of requests for materials and supplies and the processing of orders, production forecasts.
- Scheduling, Configuration and Reconfiguration. Internal tasks to the management of production operations. It includes: Evaluation of the possible configurations to achieve production through optimization algorithms, establishment of work orders for the different physical units, reconfiguration in case of problems on the plant floor.
- Coordination -- Supervisory control: Establishment of parameters to the controls on the plant floor, updating of said parameters according to the presence of events in the physical processes under predictive control schemes. Storage of information in real time, online analysis of plant floor information.
- Regulatory control - Adaptive control: Management of the system in real time, acquisition of physical variables, online evaluation of the condition of the equipment for control adjustments and generation of events

The physical processes, which are in direct contact with layer 1, we will define here as layer 0, are performed by operators - machines and are controlled by operators - systems of layer 1. See Fig. 7. There is an interaction between the different layers as well as between the internal functions of each layer. A diagram of the interactions of each layer is shown in Fig. 7. A first validation of this approach is given in Chacon et al. 2021.

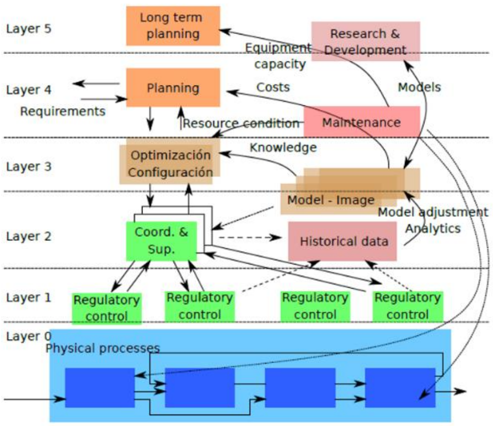


Fig. 7. Control hierarchy and its functions

The system will have a dynamic that is the result of the decisions made in the different layers of the hierarchy with respect to the immediately lower layer and of the evolution in each of the units that are carrying out the physical processes (mechanical, chemical, biological) with respect to layer 1.

Physical processes in production systems regardless of their nature (continuous, batch, discrete) are modeled, in principle, subject to temporal restrictions associated with real time, at the plant floor level, at higher levels this modeling is by events. In our case, establishing the resource model to define the control cycle is done by means of hybrid dynamics as described in Chacon et al. 2021.

We will use an extension of the definition given in Lygeros et al. 2012 for a controlled hybrid dynamic system. A hybrid dynamic system HDS is a collection

$$H = (Q, S, X, U, Y, \Gamma, i, f, g, h, Init, Dom, E, G, R)$$

where:

$Q = \{q_1, q_2, q_3, \dots\}$ *Discrete states set of processes in the resource*
$S = \{s_1, s_2, s_3, \dots\}$ *Supervisor discrete states*
$X \epsilon \mathfrak{R}^n$ *Continuous variables set*
$U \epsilon \mathfrak{R}^k$, *Regulation variables set*
$Y \epsilon \mathfrak{R}^m$, *Continuous variable outputs*
$\Gamma \epsilon \mathfrak{R}^r$, *parameters set*
$i \epsilon \mathfrak{R}$, *invariant* or physical condition associated to the output flow
$f(\cdot,\cdot,\cdot,\cdot): Q \times X \times U \times \Gamma \mapsto \mathfrak{R}^n$, *Vectorial field*
$Dom(\cdot): Q \longmapsto 2^X$, *is the domain*
$E \subseteq Q \times Q$, *transitions set*
$G(\cdot): E \longmapsto 2^Y$, *are the guards*
$R(\cdot,\cdot): E \times X \longmapsto 2^X$, *reset map*

with:

$\dot{x}_i = f_i(q_i, x_i, u_{i,}\gamma_i)$, it is the model of the process for the invariant i, for i= 1, …;

$u_i = g_i(s_i, x_i, \bar{X})$, is the regulatory control for the invariant i, for i= 1, …;

$y = h(x, \bar{X})$, are the output functions, definingy_p how the outputs obtained by measuring estimation from the process, y_m the calculated outputs using the model, $y_e \subseteq y_p$ the triggering outputs for the changige of the behavior state;

$\bar{Y}_e = \{\bar{y}_{ej}, j = 1 \dots\}$, border for y_e: $event = \{e_j, j = 1, \dots\}$, events obtained from y_p, y_m, y_e y Y_e

With the previous definition of hybrid dynamics, the relationship between the control loop of Fig. 5 and the layers of Fig. 6 is given as follows, at a given instant, the condition of the physical process (invariant), in layer 1 is defined by a model $f(\cdot,\cdot,\cdot,\cdot)$, and a regulatory control u, the events generated in the event detector by evaluating the outputs Y_e under the restrictions $\bar{Y}_e$ and comparisons between y_p and y_m in event, establish, in layer 2, the evolution in the image model Q generating the state q_i that defines the invariant, with this state the supervisor S, establishes the required setpoints $\bar{X}$ in layer 1 under the state s_i, with the setpoints in layer 1 are calculated and apply optimal (adaptive) controls. In the other layers an equivalent procedure only that this is established between dynamics and adaptive control is changed by discrete predictive control.

3.1.2 Horizontal decomposition of the value chain functions

Layers one and two of each unit perform these services autonomously or depend on an external control system that supervises the execution of the different tasks associated with each layer of decision-making, or in a combination, where some layers of control are distributed associated with the execution of the physical service and the upper layers are centralized as shown in Fig. 8.

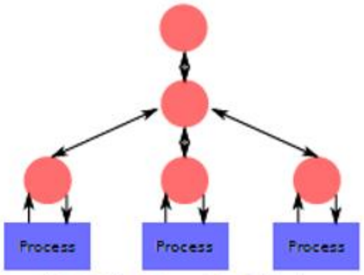
The result of the provision of manufacturing services on the plant floor is represented by a set of events that describe in a certain way the behavior of the process on the plant floor. The abstraction of the behavior for the upper layers is represented by the sequence of states $q \in Q$. The interactions between two units is given by events common to two or more units that cause the total dynamics of the system to be determined by the presence of these types of events.

3.2 Global dynamics for the production company

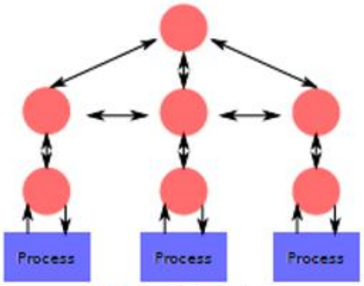
From the ontology given in the section 2, where Activity is the central element, which results from the association of a product model with respect to a set of skills established to comply with an order and that are executed by a resource are shown in the product-services-equipment cube in Fig. 9 (Chacon et al. 2019), as a result of the integration and whose description is given below.

The description of the figure follows: Product Model Plane maintains the information on how to obtain a product. It is defined as the set of services necessary on the inputs (stages to be fulfilled) in order to obtain the product. The services have a defined order of execution. The product model relates the Product axis to the Service axis. The description of the model is made using Petri nets (David et al. 2005). The Skills Map Shows information on the capabilities of a team (resource) to provide a service. Each resource has an ability (shown as rows, associated with the equipment-services plane and as the right face of the cubes in the trihedral in Figure 9) that indicates the services it can provide. The information organized in this way decouples the resources of the product giving a greater ease in the planning work as it will be shown later.

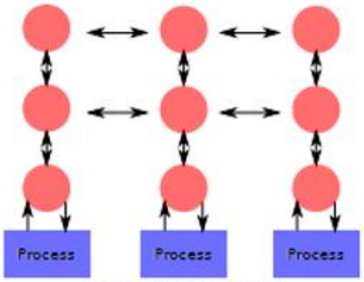
Finally, the Product Route Plan is the result (cubes) of the projection of activities on the team - product plan.



a) Centralized Supervision & Planning
Distributed Direct control



b) Centralized planning
Distributed Coordinacion & Direct control



c) Fully distributed system

Fig. 8. Types of architectures

The global dynamics of the plant results from the interaction of the activities associated with the business processes with the activities of the production processes in a feedback system as shown in figure 6. The production planning and scheduling activities serve as a link between the production activities themselves, and the business processes. The global state is the composition of the state of physical processes, the state of resources including inputs.

The dynamics of the physical process is represented, in the production programming layer, through its discrete abstractions, and the purchase and sales processes by their events, which allows knowing the global state of the plant in a complete way.

The models of each component allow to establish the consequences for each evaluation: duration, associated costs, which according to optimization criteria establishes the decision that is sent to each component where the supervision layer autonomously establishes the form of execution of the tasks necessary to complete the objective.

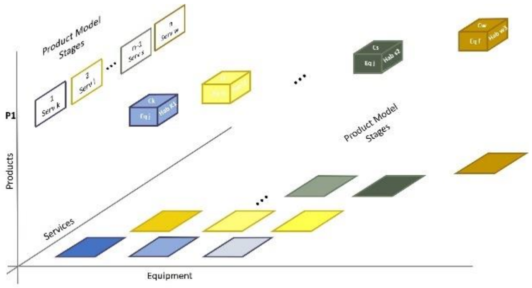


Fig. 9. Mapping Product Models and Resources onto a Value chain to accomplish a production goal. From de Chacon et al.2019

The exchange between the different units of the organization is shown in Fig. 10, which is associated with the life cycle of the product, from its conception to its manufacture and final delivery. Each organization performs physical and decision-making tasks that allow the development and construction of a product to meet market needs in an optimal way.

4 The Holonic Production Unit

The Holon concept in manufacturing has been around since the 90s of the 20th centuries and is one of the lines of Intelligent Manufacturing Systems Valckenaers 1997. A Holon is defined as a whole and part of one. Being ``one" establishes its autonomy of interaction and action. Being part of the whole, its inclusion forms a more complex entity, e.g.: cell-organ-body, cell-unit-plant. In the approach to holonic systems, a holon is considered as an element that has a decisional logical part, and a physical part that implements the physical tasks. Different control architectures have been proposed for the implementation of the concept of Holonic Manufacturing Systems (HMS) and bases and comparative studies can be found in More et al. 2019 and Derigent et al 2020. Chacon et al. 2021 propose an architecture to be used in continuous processes such as critical infrastructure systems such as aqueducts.

A Holonic Production Unit (HPU) is composed by a hierarchy of supervisors the *Supervisor Holon* and its responsible of planning, and execution of the *Activities* that achieve the manufacturing services; Activities are associated to the *Mission Holon*, similar to the Order Holon in PROSA the *Engineering Holon* that stores the knowledge of the HPU, and the *Resource Holon* that is formed by the equipment or other HPU as can be seen in Fig. 11.

4.1 The control architecture of the HPU

To define the control architecture, starting from the ontological model presented in section 2, we will focus on the resource, considering that the resource has the necessary autonomy to regulate, control, cooperate and plan its activities.

The HPU architecture to manage the internal processes and is partitioned in several resource layers as is shown in Fig. 11. The upper resource layers perform the negotiation with other HPU. It evaluates the possibilities to accomplish its part of the global goal and send an expected behavior to evaluate the whole behavior. If the composition of the system is considered viable, an agreement is achieved.

The HPU as resource, performs services and for each service a process is executed. Those process are specific for the resource and the service. This process has a behavior as is described by the Process Model. Each service has a local supervisor that drives the process. This local supervisor interacts with the global supervisor through messages to coordinate the cooperation. The global supervisor is obtained from the behavior between units given the logical (unit state) and physical (product flow) interactions.

A UML deployment diagram of the HPU software components is shown in Chacon et al. 2021.

4.1.1 The Control of the process

The vertical decomposition of the control tasks are associated with the tasks of capturing information and acting on the physical process, which includes the regulation mechanisms. The evolution of the system follows the rules defined in the point 3.1.1 and that can be seen as a concatenation of operation modes *Phi* on the state space X in an interval (t_0, t_1^-), where the final state depends on the evolution of X from an initial state x_0 to t_0. The final state reached in an interval (t_n, t_{n+1}^-) determines the initial state of the next interval (t_{n+1}, t_{n+2}^-) associated with the function *Reset* associated with each transition. For the first three modes of operation, the concatenation looks as follows:

$$\Phi_2\left(\Phi_1\left(\Phi_0\left(x_0, (t_0, t_1^-)\right), (t_1, t_2^-)\right), (t_2, t_3^-)\right)$$

The plant floor control has the measurement interface to obtain process variables and carry out regulatory control and event detection tasks that allow the control to be changed to a new operating mode through the action interface. In addition: it detects equipment values to establish possible failures and to be able to carry out maintenance tasks and captures the values of energy consumption, supplies and production values. Fig. 12 shows the components of the physical layer of the holon. Regarding CPPS, this layer corresponds to layers 1 and 2 of the CPPS model, see Fig. 1.

4.1.2 The coordination -- *supervision layer*

Coordination, carried out autonomously - cooperatively, allows two systems to interact in order to achieve common objectives. The supervisor performs goal setting for the lower layer and establishes synchronization with the other supervisors of the units that are part of the configuration currently in operation. The decentralization

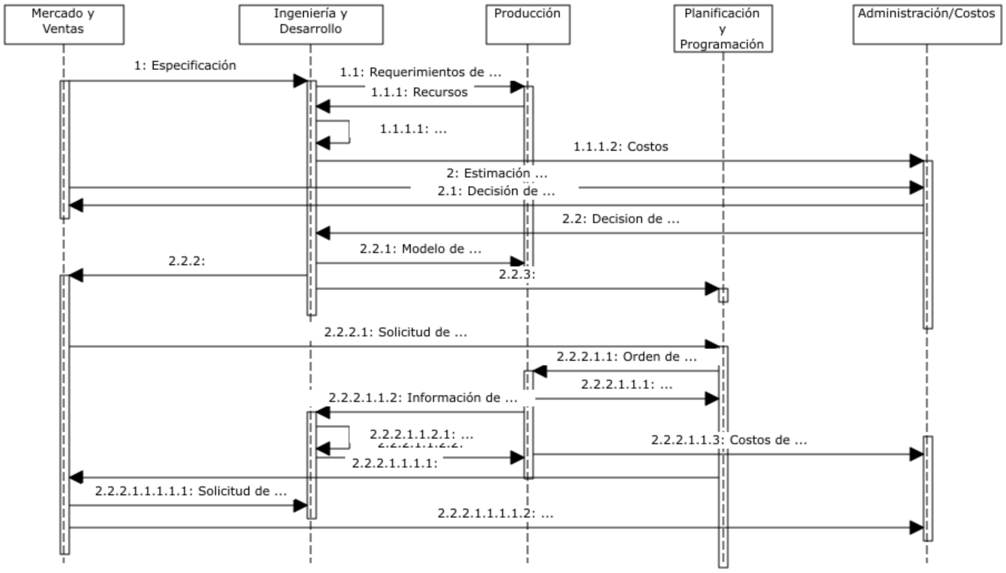


Fig. 10. Activities model for a production company from the PLM cycle

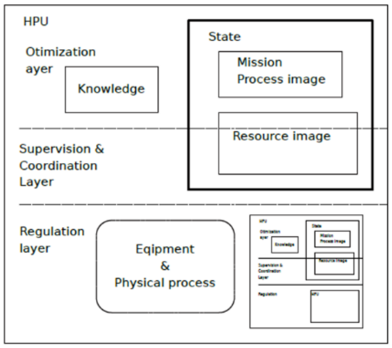


Fig. 10. Holonic Production Unit

of the supervision of joint tasks exists coordination mechanisms that are ensured at the time of the generation of the activity program for an order. The bases of the coordination mechanisms can be found in (Iordache et al. 2006, Cai et al 2010, Ye et al. 2015). This layer corresponds to layer 2 of the CPPS model

4.1.3 The planning and Scheduling layer

To preserve the autonomy of each Production Unit, at this level the Resource Holon has an image of the physical process as well as its equipment components, which allows it to determine the available production capacity, the progress status of the orders, and the ability to establish negotiations with other production units to reach production agreements. Rossit et al. 2019 indicates that the programming capacity of a CPPS system must be equivalent to that of humans through expertise, including the appearance of unexpected events.

The Resource Holon is able to integrate the knowledge of its available capacity and the advancement of its objectives to negotiate new production objectives or modify those that are in execution. The generation of new programs involves the generation of synchronization events for the coordination of the layer immediately below.

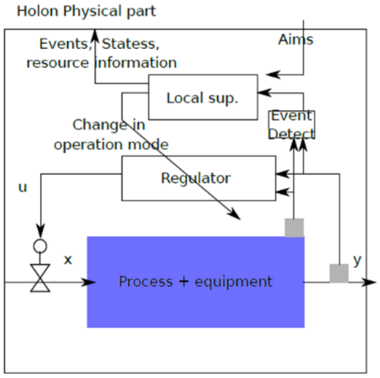


Fig. 11. Resource holon, physical part

5 Conclusion

A production system is a system of systems, where each system has its own behavior associated with each service. The global dynamics of the system results from the composition (synchronous and asynchronous) of the dynamics of each of the system components. This composition results from the physical interactions represented by flows of matter and energy, where the flows result from the internal processes of each system that are represented by hybrid systems. Maintaining the knowledge of the system in the decision layers through abstractions of the different modes of operation, allows the planning of activities and their coordination. A scheme was shown that simplifies and integrates the joint operations of the systems system in a decentralized manner.

The HPU proposal shows a viable scheme for the implementation of I4.0. The HPU exceeds the requirements presented by the CPPS for I4.0 as they suffer from integration / interaction with business processes such as required by I4.0 and they are present in the holonic approach.

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