The Holonic Production Unit: an Approach for an Architecture of Embedded Production Process

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1. Introduction

The holonic system paradigm derives from the word "Holon" that was coined by Arthur Koestler (Kloester, 1967), and it comes from the composition of the Greek word "holos" that means "the whole" and the suffix "-on" that indicates part. According to Koestler, every holon has the same structure, that is stable, coherent and its components has the same structure; the organization is invariant, the holon can be part of a bigger holon and it has parts that also are holons. This result was obtained by Koestler in the search of auto-organizational models for biological systems, where he identified structural patterns that form hierarchical embedded structures that are copies of their. This embedded hierarchy was named holarchy; this term reflects the holon trend to act as autonomous entities that cooperate in order to achieve an hierarchical system auto-organized similar to cells/weave/organ hierarchical systems in biology (Christense, 1994). In the holarchy, holons, independently of its aggregation level, have a behaviour as a whole and as parts that cooperates to reach an established goal. Inside the holarchy, holons can simultaneously belong to different groups, having precise rules that describe its behaviour. Internally, its own rules define the holon as an individual entity, with a structure and a functional model and its properties. In a holarchy, the autonomy duality, as a principal contradictory opposition, it is balanced by the knowledge model, which defines the functionality of the system as a composition of semiautonomous holons.

The Holonic Enterprise (HE) (McHugh et al, 1995) emerges based on the concepts given in the upper paragraph in order to satisfy the enterprise paradigm of having reconfigurable, open, and flexible production models, which are able to follows the dynamic of the market in a global economic-network. The HE has strategies and relationships that evolve with the time according to the business environment dynamics.

Nowadays, formal enterprises look for the accomplishment of the openness paradigm, able to reconfiguration, to be flexible by the creation of autonomous production units able to cooperate or dynamic enterprise networks build to accomplish a specific goal. In this way, an ideal organization or a virtual enterprise is a set of different production units that are geographically distributed simulating to be a unique organization with a specific localization. For a virtual enterprise, it is necessary the existence of a technological

communication infrastructure that communicate all of the units that belongs to the virtual organization (Ulieru et al, 2002).

Actually, there are several models based on the holonic approach for the manufacturing systems and the architectures that support them (Kloester, 1967), (Chistense, 1994), (Brusel et al, 1998), (Hannover, 2000), (Brussel et al, 1998), (Wyns, 1999). In (Chacon et al, 2007), it is shown a schema for a holonic production processes that incorporate complex – precise models for the whole system.

In this work, we propose a reference model for the production processes in virtual or networked enterprises, which is seen as the cooperating composition of Holonic Production Units. The relationship among the different plants of the production process is derived from the business model, the value chain, and the production flows (Cardillo et al, 2005). These Holonic Production Units (HPU) are described in terms of their components, where each one has the holon characteristics. The invariant composition procedure, without lost generality, is given by the recursive composition of the holons as was mentioned in previous holon definition.

The basic holon is composed of non-autonomous equipment (resources) that performs direct product transformation, storage and transportation tasks, direct control and regulation systems, the supervision system, and the management system for the holon. Resources can be controlled by an exclusive controller for each equipment and the set of resources and controllers shapes the controlled basic holon. This basic holon must have the capability to supervise and coordinate its own set of controllers; in this case we call an autonomous supervised basic holon. If the basic holon must be able to negotiate production goals and to synchronize the production scheduling with other basic holon to ensure a production goal; in this case we have the expected behaviour for the holon. In figure 1 it is shown the functional structure and decision elements for a basic holon.
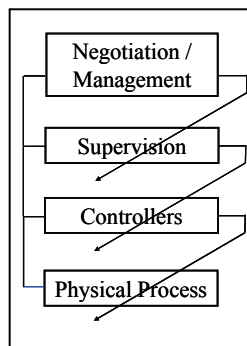

Fig 1. The basic holon

A set of basic holons or a basic holon that attain a goal is defined as the Production Unit Holon (PUH). This PUH keeps the holon structure and the control and regulation functionalities. Then, it must have control mechanisms, a supervision mechanism and negotiation / coordination mechanisms with other PUH at the same level.

In section 2 it is presented how to model formal enterprises from a holonic point of view. Section 3 describes the Holonic Production Unit that is oriented to the achievement of a goal that is derived from the value chain. In section 4, we present the holonic enterprise like a composition of Holonic Production Units. Conclusions and future works are given in section 5.

2. Modelling formal enterprises.

As has been presented in the before section, a production process must be modelled in the same way, independently if the kind of enterprise (formal or virtual) that will be organized to accomplish a production goal. The production process depends only of the value chain and the production flows. The production process necessary to obtain the production goal follows a model where each element of the value chain represents a stage of the production process. Each stage adds value to a product by transformation, transport or storage of that product across the value chain (Chacon et al, 2002) as it is shown in figure 2.

The production flow can be defined as the set of transformation stages determined by the production method using a set of resources specific for each stage (recipe) until to obtain the final product. Each stage must ensure the quality of the process and the products that are obtained.
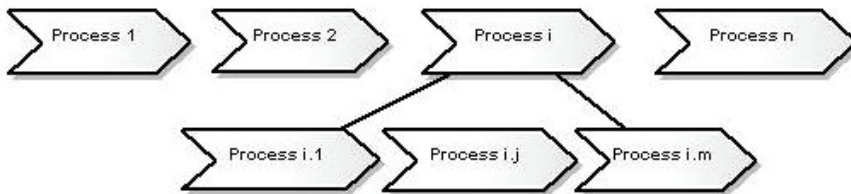

Fig. 2. The Value Chain

2.1 Description of a production unit in production process

Each stage for the value chain (raw material input / processing or transformation / storage) of the production flow is seen as performed by a Production Unit. Then, a production process is an aggregation of cooperating production units. The characterization of each production unit depends on how the resources evolve on the production process at the production unit. The resources dynamic can be: Continuous, Discrete or Event Dynamic (manufacturing), or Hybrid (for example in batch processes). Additionally, each PU performs operations that follow a recipe for the equipment that belongs to the production unit.

It is possible to find common elements that allow describing the PU in a generic way. Then a Production Unit must have:

- A process to obtain raw material
- A transformation process
- A storage process for final or intermediate products

At begin, production resources (equipment, HR, and raw material) are managed internally or requested to other PU by means of UP coordinator. Then resources are localized and translated from a UP to the UP that requires resources and intermediate/final products are translated from a UP to the client that can be extern to the enterprise or other UP. Thus, the resources localization and translation operation is responsible to guarantee the resources for a production process corresponding to a production method. The selection of the production method depends on the quality and quantity of raw material, capability and available capacity of the equipment. When the production process ends, resources are liberated and the obtained products are temporally stored, until other PU or final client request for the product.

In figure 3, we show the structural model of a PU with all its elements. This model includes the control, supervisory, and coordination/management system for each stage of the value chain. A PU drives the production methods and the internal configuration of the internal resources in order to obtain the production goal.

Using the above UP definition, we establish the basis to obtain the information that allow to fix a production schedule and to determine the state across the production process; Key Production Indicators: production quality, production capacity, expected production, etc., all of them necessaries to negotiate with other PU a production goal. A production agreement results from the production capacity and the existence actual or future of raw material.
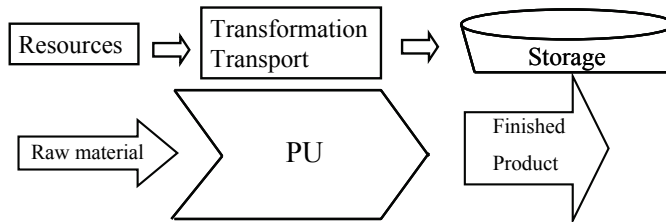

Fig. 3. Production model for a Production Unit

The structural model for the PU is obtained using UML (Cardillo et al, 2005), (Eriksson et al, 2004), (Muller, 1997), (Jacobson, www), and (WBF, www), where boxes represent classes and lines among the boxes describe relations among the classes. Lines describe three kinds of relationships: generalizations / specialization by arrows, associations by plain lines and compositions by lines with a rhombus in the end.

For the model shown in figure 4, we can see different entities that are components for a PU and its relations. Specially, it is shown an association, which record all different resource configurations, the production process, and control and supervision mechanisms for a particular production.

Also, it shows a classification for the resources used in production, that is employed by the planning function belong to the PU. The whole model has a specialization for several classes that they are not shown in the schema; each resource class has a behaviour that is described by means of a Discrete Event Dynamical System. The dynamics describes rules and operations for each class and the composition of dynamics define the behaviour of the PU.

Using the UML model shown in figure 4, a figure 5 represents the embedded procedure of making decision process for each stage in the value chain that allows considering each stage as an autonomous Production Unit.

The embedded model corresponds to the decomposition of the making decision process, which describes control procedures, supervision/coordination schemas. This reference model establishes three levels: the floor level where we can found the physical process (Transformation) and its control loops (observers, controllers, and transducers). All of them installed over the Control, Information, and Communications Technology.

In this way, the physical process is seen as the system to be monitored, supervised, and managed by an upper level that is the supervision level. Without lost of generality, a PU abstraction allows us to see as a physical process that can be part of a new stage in the value chain. This stage receives raw material, handle it, perform transformations by means of its own resources and generates new products for the next stage on the value chain or for the final client.
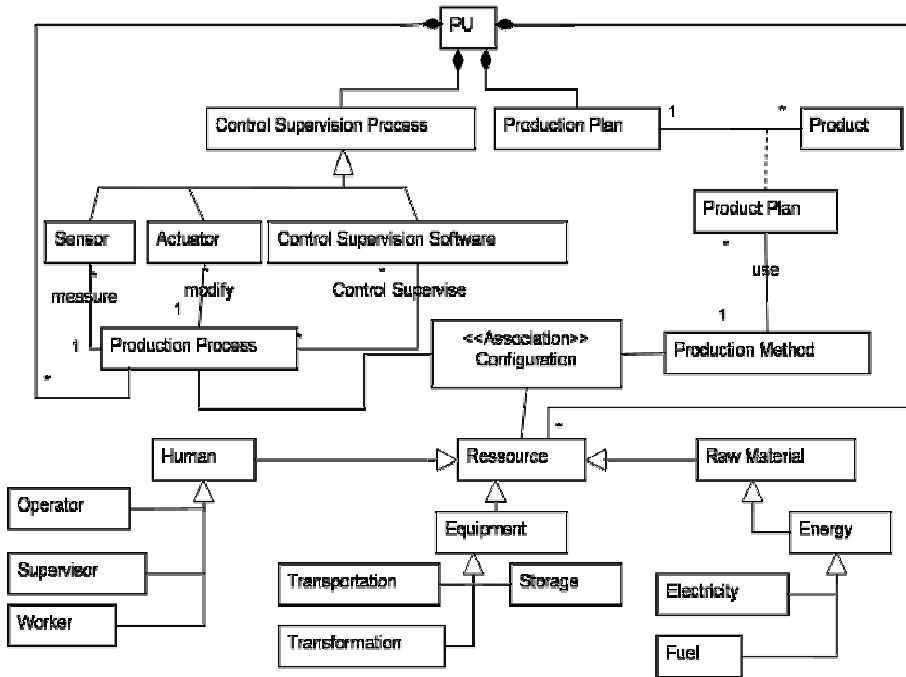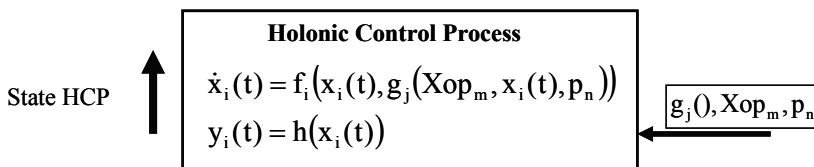
Fig. 4. The UML model for a PU

$$\text{State HCP} \quad \boxed{\begin{array}{l} \textbf{Holonic Control Process} \\ \dot{x}_i(t) = f_i\big(x_i(t), g_j(Xop_m, x_i(t), p_n)\big) \\ y_i(t) = h\big(x_i(t)\big) \end{array}} \quad \boxed{g_j(), Xop_m, p_n}$$

Fig. 5. Embedded Model of the Production Process

3. The holonic production unit

A holon for manufacturing enterprises is defined as a cooperative and autonomous construct able to transform, transport, store and/or validate information and/or physical products, [8, 12, 17, 18, 21]. A holon has the autonomy to create and control the execution of its own plans; it can cooperate with other holons to develop a viable plan in order to reach the global goal for the system. The cooperation among the holons is accomplished by means of a holarchy that evolves from the same organization. We have a holonic system.

For a holonic production system, the goal is to obtain all the facets for the decision and control procedures from the establishment of a production plan for the whole PU until the control/regulation at the floor level. The integrated automation is based upon a global vision of the production process, where each element that make part of the system must be take into account in order to control, supervise, and manage the production; see figure 6.

The automation schema is given by the construction of models that represents the PU in its structural and behavioural aspects. Control schemas ensure that the PU behaviour can be guaranteed inside a set of restrictions. The knowledge of the state of the physical system allows evaluating which will be the control actions that are viable in order to attain the desired state. At the system, the control is restraint by the accepted goal for the PU. The accepted goal is evaluated and negotiated taking into account the capabilities and availability of the PU.
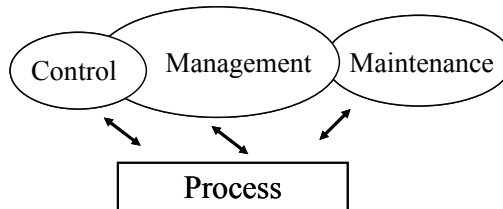
Fig. 6. Integral Automation Model of Production Systems

All the knowledge of the PU is internal to the PU, which has a behaviour that follows the physical/chemical laws for an operation mode. The composition of the laws for each component gives the behaviour of the whole PU. This description is the base to establish the control and supervision methods that can be performed by humans or by the technological system. Each production resource has a proper dynamic; the changes across the time and the information recovered from the process determine the accomplishment of the production goal or the impossibility to attain the goal due to the failure of one or more resources. Those changes must be managed by the proper PU, in order to solve internally with its own resources by means of a new internal configuration, or renegotiate in case to be necessary and establish a new internal goal.

To build a PU, it is necessary to fix implementation architecture for the PU. We propose to fix a structure composed by a "BODY" where the physical process (transformation /storage/transport) are instantiated, and they are performed using the physical assets of the enterprise, such as: reactors, warehouses, pipelines, etc. A "HEAD" that instantiate all the decision process, which are based on the knowledge of the plant, and is constituted by human and machines. A "NECK" that is the interface between the BODY and the HEAD that supports de decision making system and store, transport information, data, and knowledge of the PU; the NECK is spread on the Information & Communication Technology.

In figure 8, it is shown the correspondence between the HPU structure and the common technology found in production systems. Then, the body is the production process itself, the neck is composed by the networks, sensors, actuators, that allow obtain, transport data and by computers, industrial computers that process and store information/knowledge. Head is constituted by the humans and algorithms that take decisions.

In this way, we propose a recursive holonic structure that describes the desired composition for the Holonic Production Unit (HPU). The HPU is composed by one PU or by an aggregation of PU, which are holons. The Production Resource Holon, which be named Basic Holon results from the aggregation of basic process that are at this time controlled, supervised, coordinated, and managed.
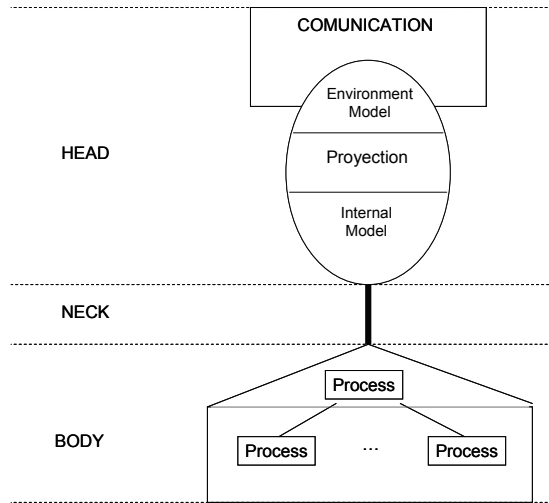
Fig. 7. Composition of a Holon in Production Process

Each basic holon has as body a controlled process, that it is formed by all the control loops. Each holon has the structure shown in figure 9, where its intelligence allows attaining the desired state by the Controller.
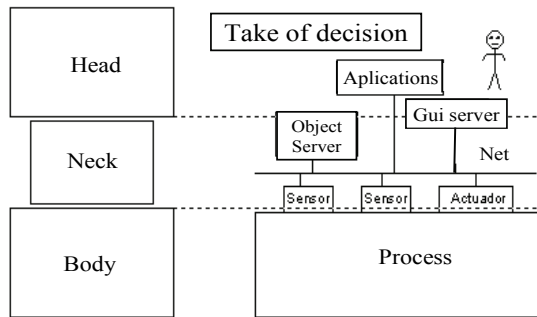

Fig. 8. Relationship between holon and the TIC infra-structure

3.1. Holonic control loop

In classical control, the basic functional unit is the control loop. If to the control loop we add as part of it, the fault detection capability and the capability of selection of new control strategies according to the operational condition, we talk about a Holonic Control Loop, the set of dynamical equations for different operational conditions must be part of the knowledge of the holon, also the controllers associated to each conditional operation. Neck for this holon is the set of elements that measure, adequate, transmit, and store physical signals from/to the process. Head has the mechanisms that allows determine the operational conditions and perform the control algorithms. Those algorithms are derived from the physical models of the plant and the control mechanisms that were selected for each operational condition.
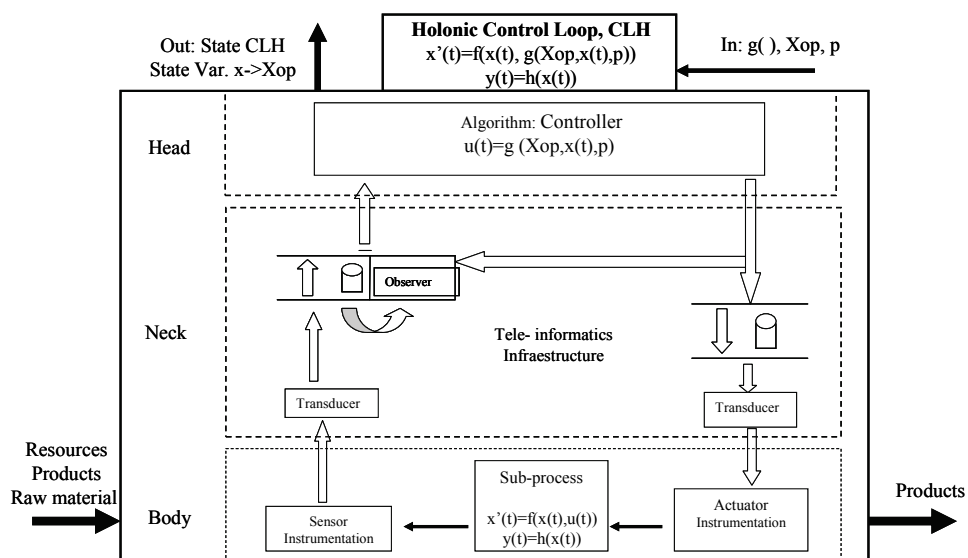
Fig. 9. Holonic Control Loop

The self-diagnostic mechanism allows to measure efficiency, conditions of the equipment; to establish requirements for raw material and equipment in order to perform the negotiation and to manage the maintenance activities. Then the holon with control loop is an autonomous system where raw material is received and final products are generated according a negotiated goal; it fix itself set-points select control strategies and control parameters. See figure 9.

3.2. Holon with process supervision

As we know, a process can have several control loops. Each control loop corresponds to an element that must be coordinated with others in order to have a valid operation. The set of control loops corresponds to a controlled holon. The process management of the set of control loops corresponds to a supervisor/coordinator. This making decision mechanism in classical supervision establishes set points, controller parameters or a control selection for a production method. If we add mechanisms to detect abnormal situations due to failures in control loops and incoherent states on the individual control loops for the global system, we have a supervised holon or holons with process supervision.

Without losing generality, the Holonic Controlled Process is a process that has i models (maybe more than one for a controlled loop), where each model has a combination of m of the nominal values of operation that can be reached with a combination of j of the controllers' types which are adjusted under an criteria/judgement determined by the loop with n parameters as it can seen in figure 10.

The Supervised Process Holon is conformed by a body that contains to the Holonic Controlled Process whose output is the state of the equipment and deviations of the consign, and whose input is the consign, type, and parameters of the controller to use, due to a set of tasks to complete that they have been evaluated and negotiated previously.
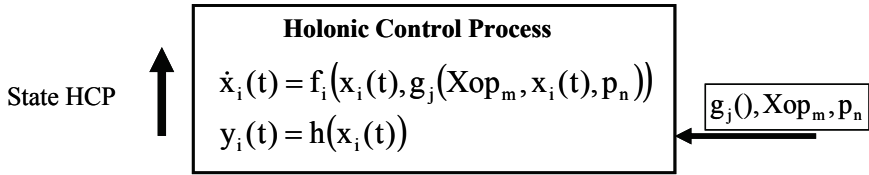
$$\dot{x}_i(t) = f_i\big(x_i(t), g_j(Xop_m, x_i(t), p_n)\big)$$
$$y_i(t) = h\big(x_i(t)\big)$$

Fig. 10. Holonic Controlled Process

Figure 11 presents the Holonic Supervised Process, the neck conformed by all of the tele-informatics architecture and applications, which allow to detect and to send events (they are able to capture, to try, to store, to adapt, continuous information in events and vice versa). The neck sends consign to the Holonic Controlled Process. From the method of production instanced and it detects the states generated by the Holonic Controlled Process. The head or fault tolerant supervisor, this conformed by the mechanism of taking of decisions capable of to establish by agreement/negotiation the set of tasks to carry out for Holonic Controlled Process, starting from the knowledge of the state of the Holonic Controlled Process and of the group of activities to complete due to the method instantiated. The model of the mechanism of taking of decisions it is seen in a natural way as a model of hybrid system that is generally implanted as a Discrete Event Dynamical System (DEDS) described by the quintuple (X, U, Y, f (.), g (.)), where X is the group it didn't empty finite of states, U it is a group it didn't empty finite of the group or alphabet of controls, Y it is the group it didn't empty of output values.
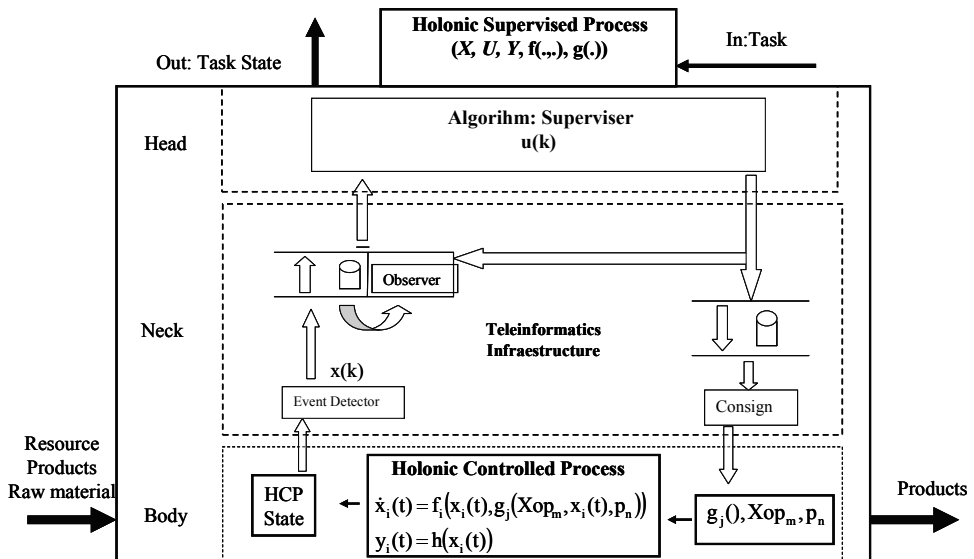

Fig. 11. Holonic Supervised Process

3.3 Production unit holon

In complex industrial processes, it is possible to have more than one supervisor where, conventionally, it is necessary a Coordinator for managing all of the supervisors. Figure 12 presents this to facilitate the coordination tasks to carry out, all of the set of Supervised Process Holon, that we will call Holonic Supervised Production.
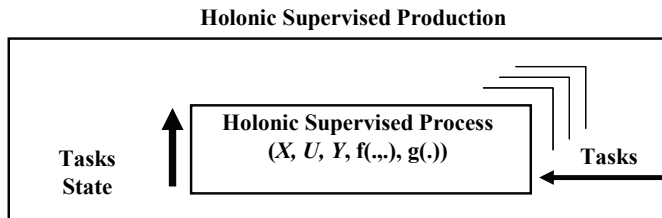
Holonic Supervised Production

Fig. 12. Holonic Supervised Production

Without losing generality, figure 13 presents the Holonic Supervised Production can have i models, each model has a combined m of tasks nominal instanced of the production method that can be reached with a combined j types of configurations which are adjusted under an approach determined by the supervisor with n of parameters.
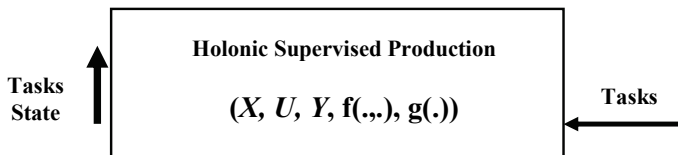

Fig. 13. Holonic Supervised Production

Thus, figure 14 shows the Production Unit Holon is conformed by a body that contains to the Holonic Supervised Production whose output is the state of the set of tasks agreed and the capacity of its resources (equipments, raw material, human resource, etc), the input are the set of planning tasks previously to complete the establish objective that it comes from an evaluated and negotiated recipe previously.

The neck is conformed by the all tele-informatics architecture and applications that allow to detect events (they are able to capture, to try, to store, to adapt, event in events information) like to leave a recipe to project the set of tasks to the Holonic Supervised Production. The head or Fault Tolerance Coordinator, this conformed by the mechanism of taking of decisions capable of, starting from the knowledge of the state of the Holonicly Supervised Production and of the set the commitments with the clients and supply, to indicate that it will be manufactured and with which recipe previously was do it the negotiation. The model of the mechanism of decisions making is seen in a natural way as a model of hybrid system, that is generally implanted as a Discrete Event Dynamical System (DEDS) described by the quintuple one (X, OR, AND, f (.), g (.)), where X is the group it didn't empty finite of states, OR it is a group it didn't empty finite of the group or alphabet of controls, AND it is the group it didn't empty of exit values.
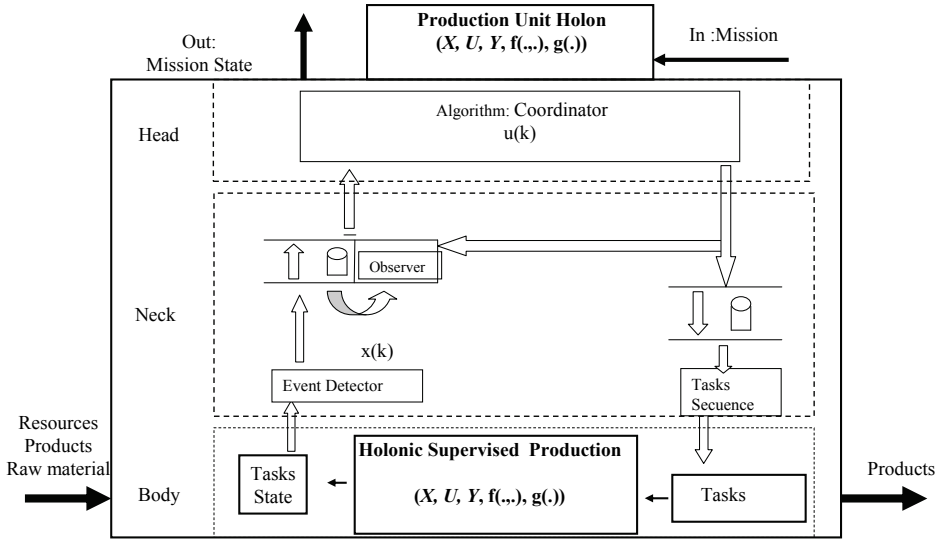
Fig. 14. Production Unit Holon

4. Holonic enterprise

A conventional enterprise is view like the set of production units associated to the chain of value of the productive process in a permanent manner since for this was constituted. A virtual enterprise is view like a set of enterprise associated to a chain of value of the productive process in a temporary manner since for this was constituted. Both use the chain of value of the productive process and for this reason the approach presented in this work, to each link of that chain of value we associate its a Production Unit Holon, see figure 15. Thus, a Holonic Enterprise this constituted for a body conformed by the set of Production Unit Holon associated to the chain of value of the productive process.

Under our focus and in order to facilitate the management to carry out, all of the set of the Production Unit Holon that we will call to Holonic Coordinated Production is shown in figure 16.
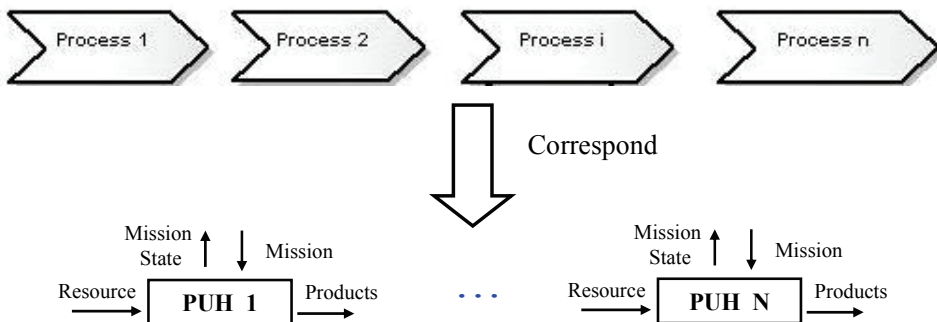

Fig. 15. Value Chain vs. Production Unit Holon

In figure 17, the Holonic Coordinated Production can have i models, each model has a combined m of tasks nominal instanced of the production process that can be reached with a combined j types of configurations which are adjusted under an approach determined by the coordinator with n parameters.
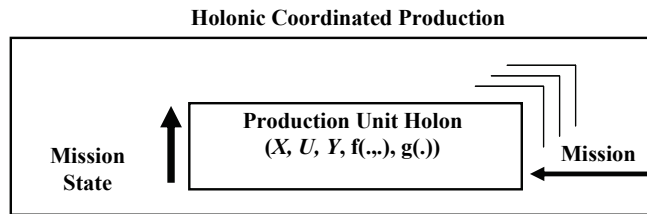
Holonic Coordinated Production

Fig. 16. Holonic Coordinated Production

The neck is constituted by the all of the tele-informatics architecture and applications, that allow to detect events (they are able to capture, to try, to store, to adapt, event in events information) like to leave a recipe to project the set of tasks to the Holonic Coordinated Production.
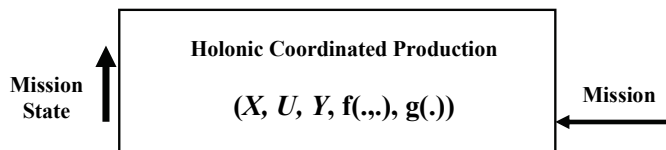

Figure 17. Holonic Coordinated Production

As we can see in figure 18, the head or Fault Tolerance Manager, this conformed by the mechanism of taking of decisions capable of, starting from the knowledge of the state of the Holonic Coordinated Production and of the set the commitments with the clients and supply, to indicate that it will be manufactured and with which process previously negotiation. The model of the mechanism of decisions making it is seen in a natural way as a model of hybrid system that is generally implanted as a Discrete Event Dynamical System (DEDS) described by the quintuple one (X, OR, AND, f (.), g (.)), where X is the group it didn't empty finite of states, OR it is a group it didn't empty finite of the group or alphabet of controls, AND it is the group it didn't empty of exit values.

4. Gratefulness

- Scientific, Humanistic, and Technological Council (CDCHT), University of Los Andes, by mean of the project I-867-05-02 –A, Production Unit Holon.
- To the program France - Venezuela, ECOS NORD: Production Enterprise Nets.

5. Conclusion and future work

In a natural manner the business model, the chain of value, the product flow and the holonic approach allow us to capture a coherent model of the production process in all of their globallity and complexity giving origin to the shown embedded model.

The description invariant embedded presented of the Holon in production processes allows us to catch in a clear and precise way, the holonic recursive definition of the biology starting from the holarchy cell/tissue/organ like holonic functional basic unit of a body.
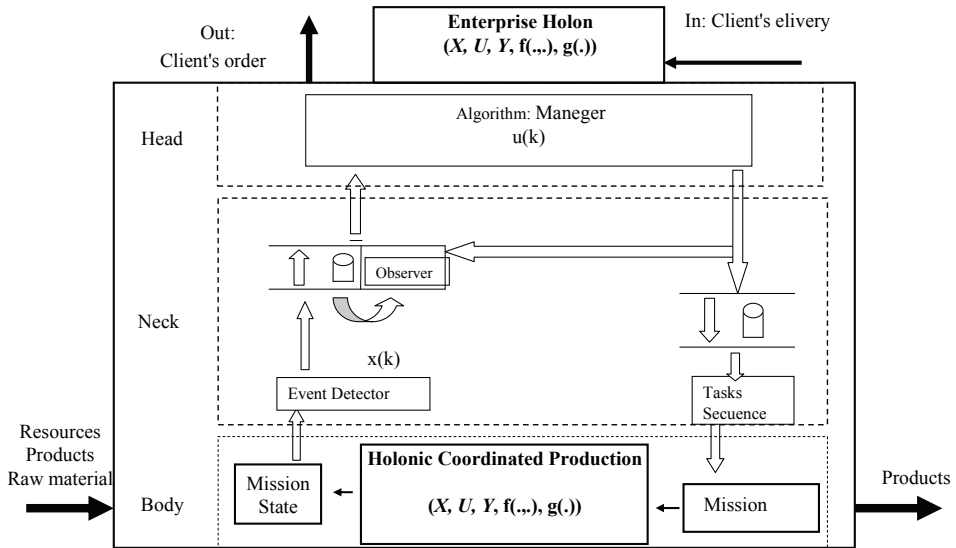

Fig. 18. Enterprise Holon

This proposed recursive structure of the Holon to describe production processes allows us to present one scheme that is topologically the same, which should be configured in each of the instances required to model a company, including the established description of layers of the standard SP95.

Our future work is devoted to complete a set of elaborated cases of study, where we show the implementation of these concepts in several domains.

It is necessary to complete the description of the proposed Production Unit for each case. The negotiation mechanism must be implemented using a protocol that arrives to an agreement, which determines the cooperation among the units making part of the holonic enterprise.

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Advances in Robotics, Automation and Control

Edited by Jesus Aramburo and Antonio Ramirez Trevino

The book presents an excellent overview of the recent developments in the different areas of Robotics, Automation and Control. Through its 24 chapters, this book presents topics related to control and robot design; it also introduces new mathematical tools and techniques devoted to improve the system modeling and control. An important point is the use of rational agents and heuristic techniques to cope with the computational complexity required for controlling complex systems. Through this book, we also find navigation and vision algorithms, automatic handwritten comprehension and speech recognition systems that will be included in the next generation of productive systems developed by man.

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