Models and concepts for integration of classical manufacturing systems into holonic systems

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Abstract – **Holonic control systems represent a new paradigm that transfers principles and examples inspired by the organization pattern of systems from the living world to the domain of manufacturing systems. This article presents a few social holonic models and their applicability in the manufacturing domain, which allows an easy integration of classic control systems into holonic systems. The last part of the article presents a practical example of integrating a robotic assembly cell into a holonic system. The example we present is under implementation and its purpose is to validate the suggested models.**

Index Terms—**holonic manufacturing systems, intelligent control, robotic assembly cell**

I. INTRODUCTION

Holonic Manufacturing Systems originate in the observations of writer Arthur Koestler about the way biological systems and social organizations are constructed. Koestler introduces in 1969 the term „holon", as a combination of two words from the Greek "holos", meaning "whole" and "on", meaning "particle" in his essay „The Ghost in the Machine" [1], to describe the idea that components within a complex system behave both as a *whole* which can be divided into subcomponents and as a *component* which belongs to a greater whole.

The applicability of holonic concepts to the domain of manufacturing systems has first been mentioned by Suda in 1990 [2] and referred to the development of a new generation of manufacturing control systems characterized by modularity, autonomy, cooperation, distribution and having a similar organization pattern to the systems of the living world. The basic idea is that a system is more stable and has a higher reconfiguration capacity if it is composed of intermediate stable forms than having a monolithic structure.

Suda's observations led in 1993 to the launch of the HMS project (Holonic Manufacturing Systems) within the IMS programme (Intelligent Manufacturing Systems) [3]. A significant number of scientific papers reveal the results obtained both by the members of HMS consortium as well as by other small or medium institutions which performed research activities in this domain. These papers include synthetic and analytic researches regarding the evolution and present demands of manufacturing systems [4], [5], architectural specifications and holonic models [6],[7[,[8], migration strategies [9], case-studies and practical implementation examples [10].

This article focuses on a holonic architecture which can allow an easy integration of classic controlled systems within the intelligent control systems. The constructed holonic examples are inspired from the human body and social organizations and they correspond to the principles stated by writer Arthur Koestler [1].

The following part of the article presents a few social holonic examples and the third part discuses their analogy with the domain of manufacturing systems. The fourth part approaches a few aspects concerning implementation of holonic models within the control of manufacturing systems and the fifth part of the article presents a practical example of assembly-cell integration within an intelligent control system.

II. SOCIAL HOLONIC MODELS

Fig. 1a) shows the individual as an intelligent basic entity within a social organization. Generally speaking, the individual is constituted of an intelligent component, represented by the individual's brain or mind, and a set of integrated components (members, organs), which apparently lack intelligence, as compared to the brain. These components are very well inter-connected and subordinated to the intelligent component. There is yet a certain level of autonomy (the case of organ transplants) and a reaction capacity to the environment's actions (based on stimulus-response principle) independently achieved in relation with the intelligent component, the brain.

To consider this organization pattern in terms of holonic concepts we could consider the human body as representing a holon of simple intelligence, composed of a single intelligent component and a set of rather unintelligent but able-to-integrate holons subordinated to the intelligent component.

If a certain task must be achieved, further analysis of the organization pattern of individuals reveals the principle of the working teams. A team is generally made up of several individuals out of whom one is assigned to coordinate and supervise the activities, as illustrated in Fig. 1b).

The team can therefore be viewed as a whole constituted of several intelligent members, subordinated in a certain degree towards a special member of the team, having management responsibilities. However, in case of a team, the decisions are not taken by the coordinating component, as in the individual's case, but they are the result of the interaction between the team and the other members.

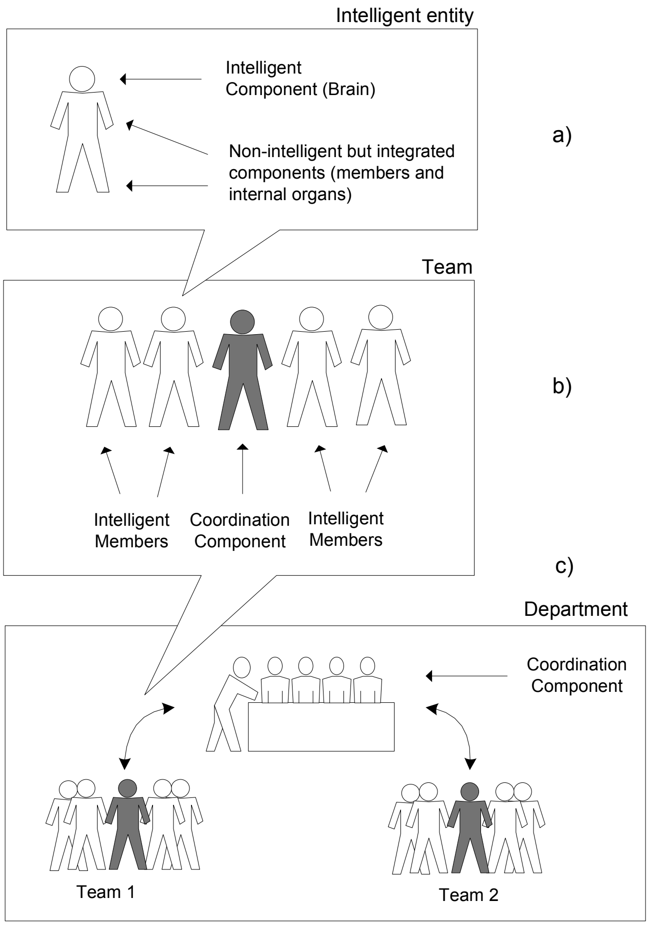


Fig. 1 Social holonic models

From the point of view of holonic concepts, the team can be viewed as a holon of complex intelligence, composed of several holons of simple intelligence.

If we were to consider hereinafter the case of a department within an organization (Fig. 1c), we could ascertain that the department is composed of several teams and a coordinating unit, similarly organized and functioning as the team. In other words, the team principle can be noticed on all the superior levels, recursively applied (teams of teams) and leading to hierarchies

Three types of holons were identified, hereinafter referred to as type I,II and III holons:

- *Type I holons* - unintelligent but able to integrate holons, very hardly physically interconnected, having a low degree of autonomy (displayed by means of a stimulus-response behaviour) and subordinated to an intelligent component;
- *Type II holons* – holons of simple intelligence, composed of several type I holons and an intelligent component;
- *Type III holons* – holons of complex intelligence, composed of several type-II holons, among which one coordinates and supervises the holon activities and represents the communication means with other holons of the same type.

III. ANALOGY WITH THE DOMAIN OF MANUFACTURING SYSTEMS

As Image 2 shows, a type I holon (named H1) can be represented in the domain of manufacturing systems by a controlled automation device of classic form, as a robot for example, a conveyer controlled by a PLC or a numerical control machine. A type II holon (named H2) can encapsulate one or more such devices together with an intelligent component. We could consider an assembly cell made from an assembly robot and a set of transportation and fixturing devices (Fig. 2) as an example for this type of holon, all together working under the coordination of an intelligent software component. Similarly, we can consider the case of an intelligent conveyer obtained by associating to a classical conveyer an intelligent component which can accept and serve commands for transportation of some products/components towards certain destinations.

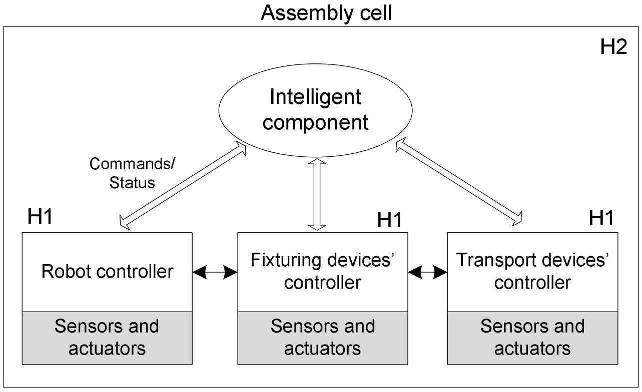


Fig. 2 Type II holon

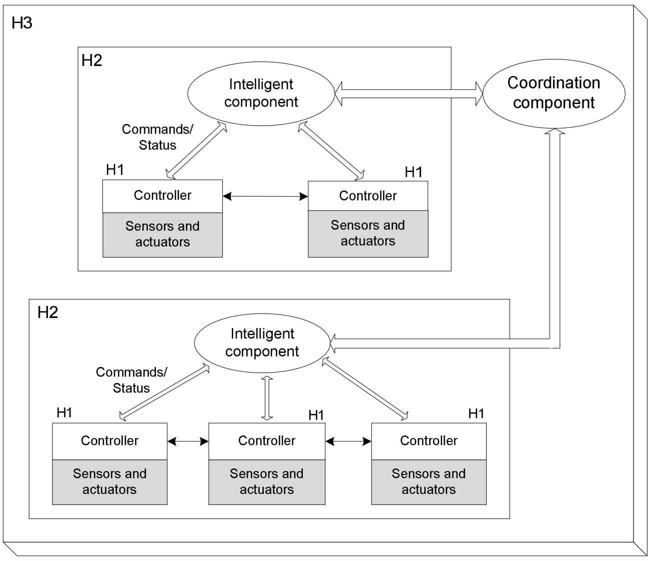


Fig. 3 Type III holon

More such intelligent devices (type II holons) can form a production unit that is coordinated by an intelligent software component of superior level and represents a type III holon (**Error! Reference source not found.**). As an example for this type of holon we considered the case of several machining stations (type II holons) positioned along the belts of an intelligent conveyer (type II holon). The coordination component receives the production order and issues optimal execution plans by negotiating with the machining stations. The task of the intelligent conveyer is to lead the semi-manufactured components towards the stations assigned by the coordination component to process them.

The concept of type II holon of *simple intelligence* in this article has in view the following:

- Holon's ability to autonomously perform certain operations on a component/product;
- The ability to communicate with other entities inside the system it is part of so that it receives commands or supplies information concerning its working status.
- Decision-taking ability concerning the priority-based execution of the received orders;
- Ability to exhibit offered services and requests at system entry;
- Fault tolerance.

A type III holon, defined by *complex intelligence,* must further supply the following characteristics as compared to a type II holon:

- Ensure exposure of aggregated capabilities resulted from aggregation of constituent type II holon capacities;
- Possess capacity of distributing the activities inside it so that it ensures a local optimum;
- Allow reception of more complex operational plans further to be decomposed in activities assigned to the systems inside it;
- Elaborate more complex solutions to provide working continuity in case of fault of component sub-system (fault tolerance);
- Ensure integration or easy departure of a type II holon to/out of the system it represents.

More complex structures formed of several type-III holons can be represented also by type III holons in a recursive manner.

IV. ASPECTS CONCERNING IMPLEMENTATION OF HOLONIC MODELS

The widely accepted solution within the holonic community concerning implementation of the intelligent component of a holon has in view the use of technologies based on intelligent agents [11]. The intelligent agents or multi-agent systems represent a very attractive instrument of software engineering used to develop systems with distributed data, control, intelligence or resources, the domain of manufacturing systems including a multitude of cases falling into this category.

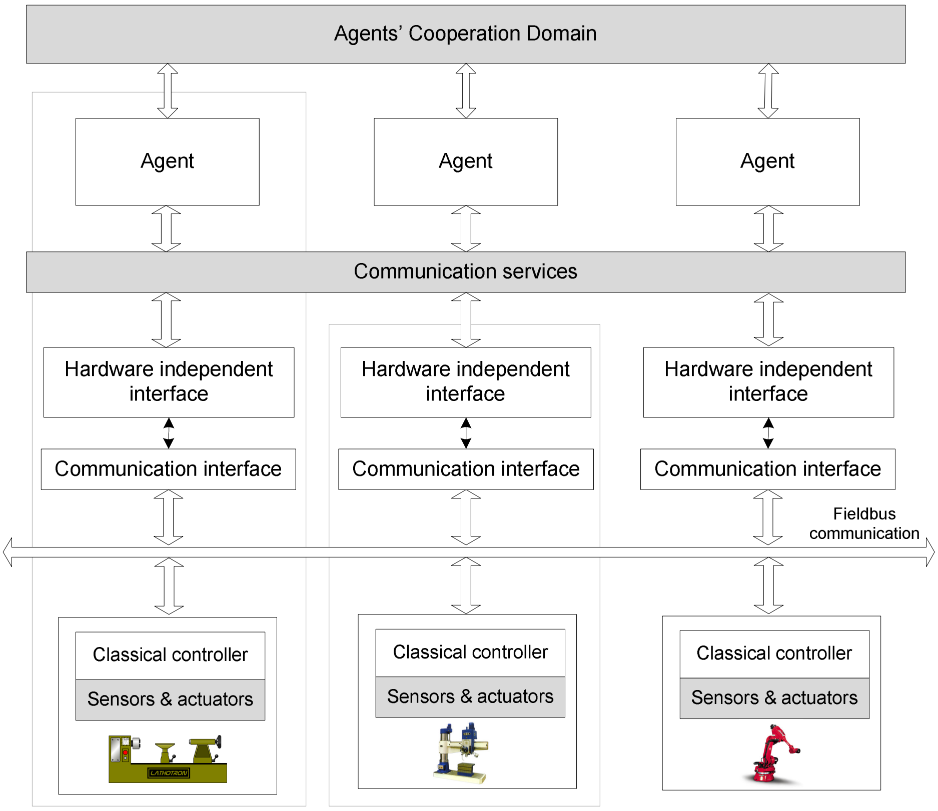


Fig. 4 System general architecture

Present controllers of automation devices do not generally possess enough resources to encapsulate a higher level of intelligence in order to be integrated into a distributed intelligent control system. That is why the solution suggested by the researchers as a first step in migration towards holonic control systems has in view separation of the control application of a device into two components [12]: a component to run inside the controller embedded in the device and which must ensure data reading from the sensors and direct control of actuators, and a (intelligent) component to run on a more evolved platform, with the purpose of ensuring integration of the device into the system and coordination of its activities in relation with the system goals. Subsequent developments aim at integrating both components into a single controller which would significantly simplify the system's communicational architecture.

The general architecture embraced in this article is presented in Fig. 4. The intelligent components of holons were represented by modules called as *Agent.* An agent has been assigned to each physical device but there are also pure informational agents fulfilling coordination activities. The coordination component of a type III holon is such an example and it is in charge with the unitary function of the holon.

Agents communicate in-between through a *cooperation domain*, using a high-level communication protocol. The agents associated to the physical devices can communicate with them by means of communication services provided by the distributed environment they operate in. For example, the agent associated to a device can run on a PC system and the component which ensures the *hardware independent interface* of the device can run on an embedded system functioning as a "bridge" between two types of networks. The communication between these two components might be done with the help of a client-server type of services supported by the operating environment.

The hardware independent interface ensures the abstraction of the specific commands of a physical device, providing the intelligent agents with a high level set of services and commands. Thus certain physical devices offering similar services can be administered by the same type of agent even though their own communication interfaces are different.

V. PRACTICAL EXAMPLE OF ASSEMBLY CELL INTEGRATION WITHIN A HOLONIC SYSTEM

This section presents a practical example of a classically controlled manufacturing system integrated within a holonic system. The classical system considered here is represented by an assembly cell described in detail in the following paragraph.

The assembly cell

As Fig. 5 shows, the assembly cell is formed mainly of a SCARA assembly robot, transportation and fixturing devices.

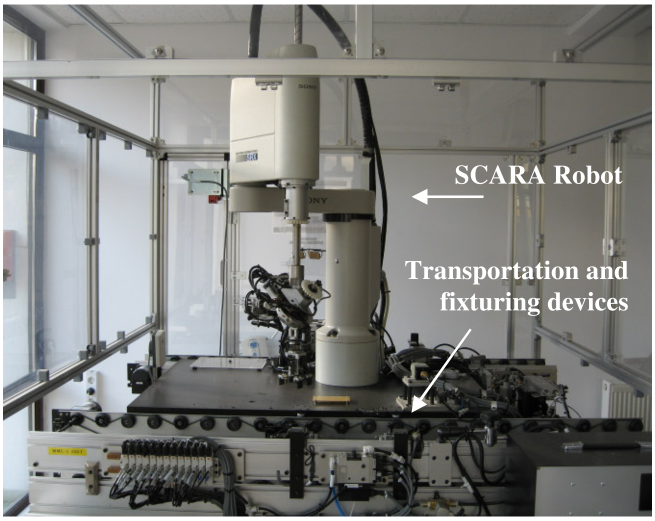


Fig. 5 The assembly cell

As for the control is concerned, the cell is equipped with two controllers (Fig. 6), one represented by the robot's controller and the other one by a PLC running applications for the control of transportation and fixturing devices. The two controllers are connected and intercommunicate by digital inputs/outputs. Furthermore, both controllers have RS232 communication ports allowing them point to point communication with a device external to the cell, using a user-defined protocol.

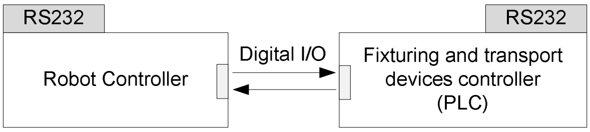


Fig. 6 Cell Controllers

Holonic model of the assembly cell

Fig. 7 presents the architecture of the holon corresponding to the assembly cell. It includes the applications from the two controllers of the cell, the software components for the hardware independent interfaces and an intelligent component called *Cell Agent*.

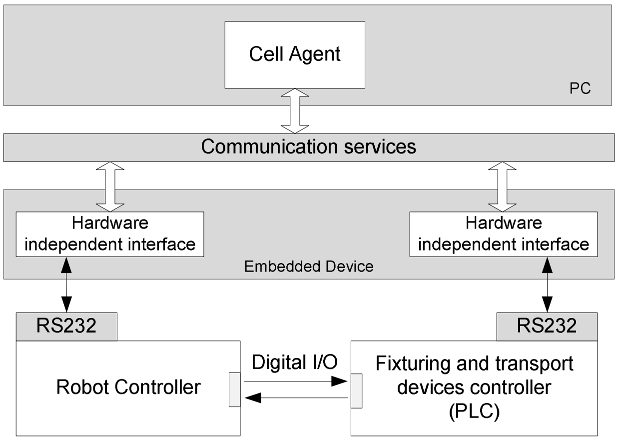


Fig. 7 Assembly cell holon

In the current implementation the components for the hardware independent interfaces run on an embedded device, while the cell agent runs on a PC-like computational system exhibiting advanced processing capabilities. The communication between the agent and the hardware independent interfaces uses a client/server mechanism over the TCP/IP protocol.

The embedded device can be seen as an additional controller attached to the cell ensuring both physical communication interfacing (RS232-Ethernet) as well as the logical one, providing the intelligent agent with a set of high level commands and services.

Operational model of the holonic system

Fig. 8 presents the simplified operational model of a holonic assembly system containing the above-mentioned assembly cell.

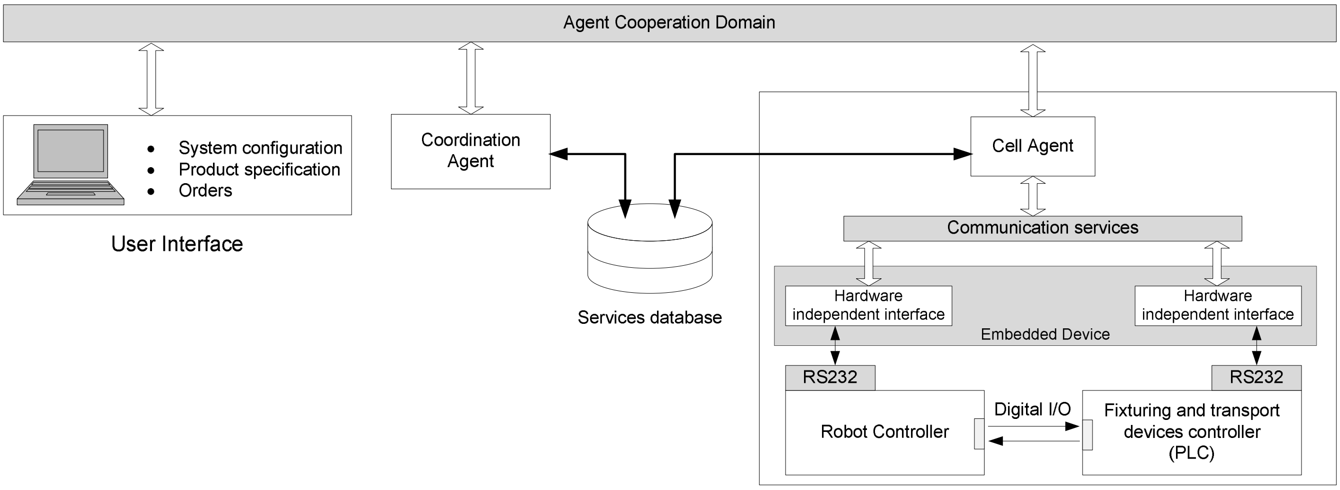
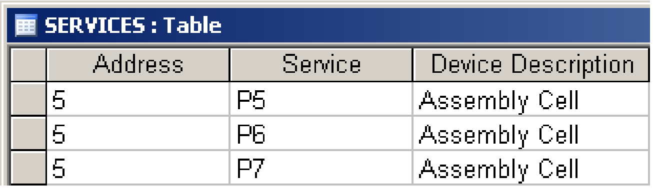


Fig. 8 Operational model of the holonic assembly system

The user interface allows one to define a product type as a set of simple assembling operations of pick and place type. Once defined, the product type can be stored in the robot controller.

Service database contains an association between the system devices and the services they offer. Table from Fig. 9 can be given as an example, assembly cell with address 5 is associated with services having codes P5, P6 and P7, signifying the products it can conceive.


SERVICES : Table

Address	Service	Device Description
5	P5	Assembly Cell
5	P6	Assembly Cell
5	P7	Assembly Cell

Fig. 9 Example of data stored within a service database

Once a new type of product is defined and saved into the memory of the assembly cell (robot controller), then an update of service database is necessary, signifying that new information containing association between the type of product and the address of the assembly cell must be added. The information in this database is used by the system's coordination agent for the purpose of finding the system devices able to perform a certain service.

Working scenario

The following paragraph presents a scenario concerning the execution of product orders by the holonic system and finally underlines the advantages given by the chosen model.

Let assume that a user launches through the system user interface a command to construct/manufacture three P5 products. The command is taken by the system's coordinating agent which first consults the service database to determine the resources in the system able to supply the service having code P5. Considering the service table in Fig. 9, the only device able to perform the required service is an assembly cell of address 5.

The next step is to interrogate the resource for its availability and time factor to complete the product. If resource is available, it will be contracted.

If there are more resources within a system able to supply a certain service, the coordinating agent will have to find a solution to distribute activities such as to ensure optimum time to complete the products.

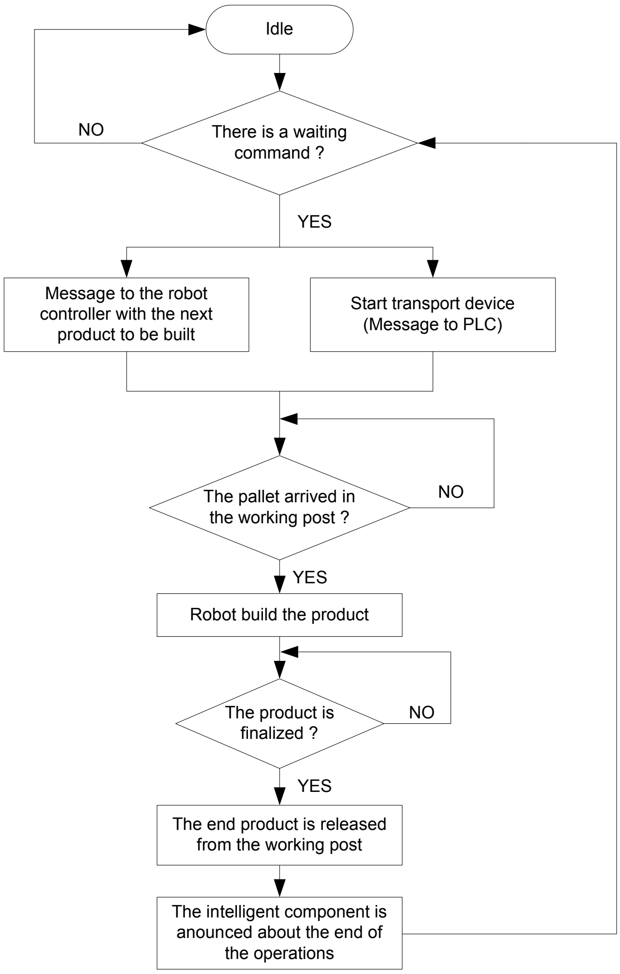


Fig. 10 Organizational chart of activities inside the holon of the assembly cell

Fig. 10 presents the organizational chart of activities inside the holon of the assembly cell, which are to serve the received orders. During the process of product completion the intelligent component communicates both with the robot controller (information messages about the product that must be completed) and with the controller of the fixturing and transportation devices (transportation requests or information about completion of a product).

Once a product is completed it leaves the working post and the intelligent component can move on to create a new product (if there is an order in this respect).

Benefits of the above-mentioned model include:

- Modular construction;
- Wide range of products – the same robot program allows creation of several types of products using specific description for each;
- Ability to deal with rush orders. If a holon receives a command of high priority, execution can be done immediately after completion of current operations.

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