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The open-control concept in a holonic manufacturing system (RAAD 2009)

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Abstract. Nowadays, the advances in information technology and electronics made possible attaching devices with decisional and communicational capabilities to almost all of the entities present in a Flexible Manufacturing System. This allows the passage from the classic centralized control approach to a fully decentralized approach where each entity has its own objectives, making it very hard for the global system to achieve a global objective like minimizing the production makespan. In this context this paper proposes a new control concept in which commands from a superior level are not sent in a rigid manner but rather as recommendations. Open-control, along with the holonic manufacturing concept tries to offer the tools needed to face the rising complexity of Flexible Manufacturing Systems. After introducing the open-control paradigm, we illustrate one possible implementation based upon a holonic approach and applied to a job shop production system, containing multiple networked robot workstations.

Keywords. Open-control, holonic manufacturing systems, Contract Net Protocol

1. Introduction

To be competitive, manufacturing should adapt to changing conditions imposed by the market. The greater variety of products, the possible large fluctuations in demand, the shorter lifecycle of products expressed by a higher dynamics of new products, and the increased customer expectations in terms of quality and delivery time are challenges that manufacturing companies have to deal with to remain competitive. Besides these market based challenges, manufacturing firms also need to be constantly flexible, adapt to newly developed processes and technologies and to rapidly changing environmental protection regulations, support innovation and continuous development processes (Nylund et al, 2008). Although the optimization of the production process remains a key aspect in the domain of fabrication systems, adaptive production gains more and more field (Sauer, 2008). Flexible manufacturing systems should be able to quickly adapt to new situations like machine breakdown, machine recovery due to physical failure or stock depletion and also face rush orders (Borangiu et al, 2008).

In recent decades, scientific developments in the field of production have defined new architectures including the heterarchical/non-hierarchical architectures that play a prominent role in FMS. This paper is an extension of the work in (Raileanu et al, 2009), describing an instantiation of the open-control paradigm, the societal implicit open-control, using the holonic manufacturing concept. This paradigm is an extension of the previous work in the domain of heterarchical control (Trentesaux, 2007) and includes the concept of implicit control in addition to the traditional explicit control. The structure of the paper is: introduction of the open-control paradigm, its description and motivation in section 2, a detailed description of the static model of the fabrication system using the holonic concepts is presented in 3, in 4 there are presented the physical infrastructure and, the experiments done and their results and the paper ends with the conclusions and perspectives resulted from the current work.

2. Motivation

Traditional approach is mainly associated to the initial CIM (Computer Integrated Manufacturing) concept and usually leads to centralized or hierarchical control structures. Due to the complexity of manufacturing problems, the usual practice has been to split the overall problem into hierarchically-dependent functions that operate within decreasing time-ranges, such as planning, scheduling and control and monitoring. This traditional approach is known to provide near optimal solutions, but only when hard assumptions are met, for example, no external (e.g., rush orders) or internal (e.g., machine breakdowns) perturbations, well-known demands, and/or supplier reliability. Since reality is rarely so deterministic, this approach rapidly becomes inefficient when the system must deal with stochastic behaviour.

The above observations have led researchers to define a second approach to designing control architectures.

These control architectures, also called emergent or self-organized, can be categorized in four types (Bousiba et al, 2002): bionic & bio-inspired, as proposed by Okino (Okino, 1993) and Dorigo & Stützle (Dorigo et al, 2004); multi-agent, as proposed by Maione & Naso (Maione et al, 2003); holonic, as proposed by Van Brussel (Brussel et al, 1998); and heterarchical, as proposed by Trentesaux (Trentesaux et al., 1998). An analysis of the state-of-the-art has been recently published by Trentesaux (Trentesaux, 2007). His main conclusion is that the expected advantages of such architectures are related to agility: in the short term, such architectures are reactive and in the long term, they are able to adapt to their environment. However, these last control architectures suffer from the lack of long-term optimality, even when the environment remains deterministic, which can be called “myopic” behaviour. This is the main reason why such control architectures are not really used by industrialists at the moment.

The paper presents an extended model for the global control paradigm, in which traditional control is augmented by a new kind of control: “implicit control”. In this paradigm, entities can be strictly controlled hierarchically and, at the same time, they can be influenced heterarchically by their environment and/or by other entities. This paradigm would make it possible to design control systems that are both agile and globally optimized, thus reducing the myopic behaviour of self-organized architectures and increasing the agility of traditional architectures. Combining the two types of control in the same architecture creates new challenges since the two types of control must now be managed and integrated within the larger control paradigm.

The work in this paper focuses on the type of control in which an entity tries to achieve its own goals with respect to the global system objectives by the means of a dialogue with the other entities; the entities can be resources or active products, both equipped with decisional and communicational capacities. An active product is an entity that is able to inform, communicate, decide and act in order to reach its goals in solving resource allocation and routing problems. (For more details on the typology and advantages of active products, (Zbib et al, 2008)).

The control principle briefly described above will be further called in this paper open-control, according to (Sallez et al, 2009) because of the capacity of subordinate levels to receive orders from upper control levels through direct orders (explicit control) and recommendations (implicit control), in which case they exhibit local decisional capabilities to follow their own objectives enabling so the easy addition and removal of entities.

Based upon the relations between different control levels, Fig.1 shows the two kinds of control: the explicit control, in which the entities from lower levels are subordinated directly to entities on a higher level through an obligatory control relation (e.g., master-slave) and the implicit control, in which the entities at each level are influenced by an intermediary optimization mechanism but not necessarily controlled.

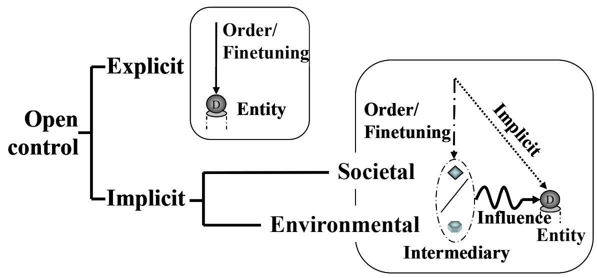

Fig.1 Control typologies present in the open-control concept

Implicit control involves influencing entity behaviour by the fine-tuning the parameters of the optimization mechanisms. This type of control works in two stages. First, through top-down order or fine-tuning, the controller level directly affects an intermediate entity that plays a role in a societal or environmental optimization mechanism. Then, an information exchange (peer-to-peer dialogue or a diffusion process) influences the behaviour of the other entities on the same level.

Taking into account the way the upper control level influences the lower levels, implicit control is of two types:

I. **Implicit control via a societal Optimization Mechanism (OM)**. In this case the upper level either fine-tunes the partial view of a collective property inside an entity, modifying its behaviour and then this entity influences the others through dialogue, or the upper level changes the dynamics of the dialogue in the societal OM by modifying the dialogue parameters inside the entity. The key element of implicit control using a societal OM is the dialogue between entities which leads to the two characteristics of holonic manufacturing systems, autonomy and cooperation (Koestler, 1967). This is why this concept offers good means of implementation for semi-heterarchical control systems which under normal conditions work under a hierarchical structure but when perturbations take place each entity uses its own decisional capacities to continue production (Ex.: staff holon proposed in PROSA, Brussel, 1998).

II. **Implicit control via an environmental OM.** This type of control is performed via the informational environment in two ways: the first involves acting on the data directly (e.g., creating, updating, erasing), while the second involves fine-tuning the parameters used by the environmental optimization mechanism (Sallez et al, 2009).

3. Holonic model of the fabrication system

Based on the PROSA reference model (Brussel et al, 1998) and on the entities and production domains presented in (Nylund et al, 2008) we identified into a fabrication system the following base elements: resources, products (blueprints) and orders in production represented by the physical products which are fabricated. Because the entities in our fabrication system are almost all equipped with decisional capabilities we decided to structure the system according to the holonic principles and implement an implicit societal open-control which will confer both the adaptive and optimality characteristics in its operation. The following elements, presented in Fig.2, have resulted after applying the holonic scheme to the flexible manufacturing system: resource holons (RH), product holons, order holons (OH) and coordinator holons (staff holon according to PROSA).

The order holons, the first key point of the fabrication system, represent the client's orders in real-time and are composed of the following informational and physical parts: an augmentation module which enriches the holon with decisional (information processing), communicational (information transport) and memorization (information storage) capabilities , the pallet which associates with the fabricated product along the production phase providing it transportation services and the passive product which is fabricated/assembled on the pallet. The structure of an order holon emphasizes the recursive propriety of a holon which can in turn be composed of other holons. In this case the order holon contains two resource holons, a pallet used for transportation and an augmentation module used to process information, and a product holon representing the blueprint containing the operations needed for execution.

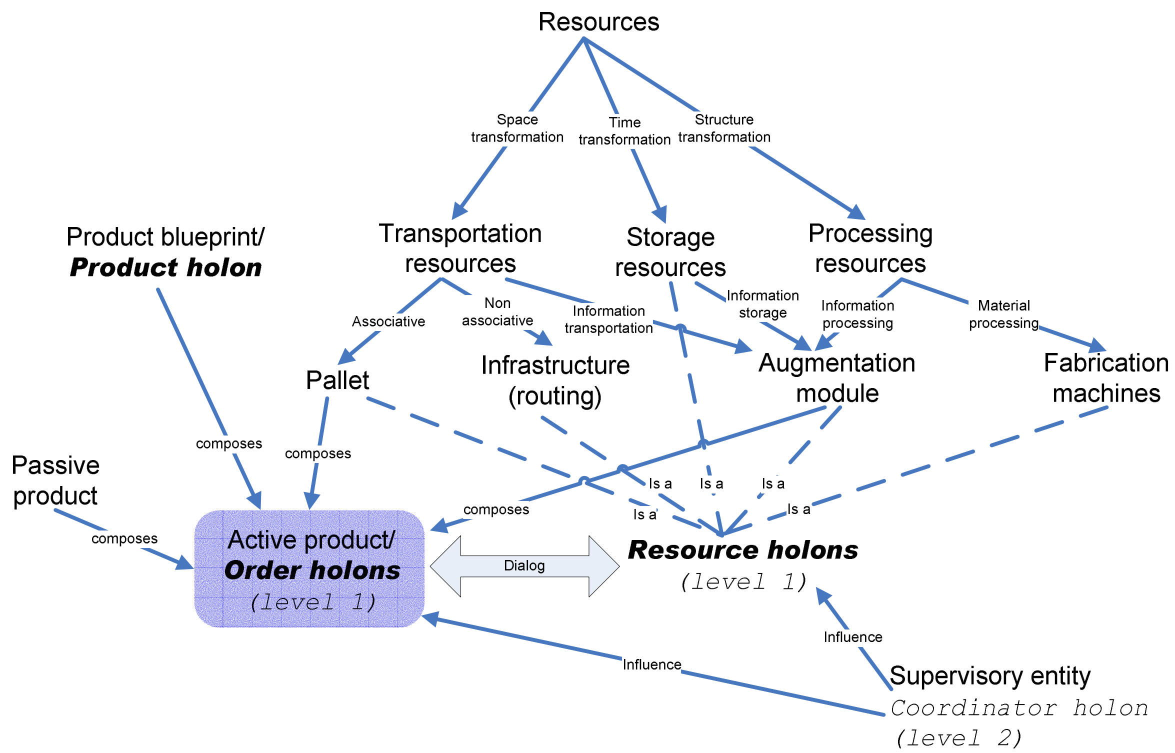

Fig.2 System components (static model)

The second key point of a fabrication system, the resource holon, is composed of an informational part responsible for decision making, control and communication and a physical part responsible with the physical processing (e.g.: mounting a piece on the product, image recording, etc). Depending on the type of operation performed by the resource the system is composed of the following basic types of resources: processing type offering structural transformation services, transportation type composed of infrastructure (Ex.: conveyor belt or conveyor segment) and mobile entities (Ex.: mobile shuttle/pallet) which together offer spatial transformation services and storage type offering time transformation services.

Moreover, each resource can be further classified, according to the entity upon the function is exercised, into information processing (as is the case of the augmentation module) and material processing (as is the case of an industrial robot working upon a product).

For the logical part of the system to be in conformity with the societal open-control concept proposed, the entities of the system are distributed on a two layer architecture, a low decisional level and a high decisional level. Usually a factory is composed of 3 levels (Sallez et al, 2009): strategic problem solving at the top (level 3), tactical problem solving in the middle (level 2) and operational problem solving at the bottom (level 1), our architecture taking into account level 1 and 2. The low decisional level (level 1) is composed of autonomous entities, OHs and RHs, which dialog between them in order to optimize their production schemes. The high decisional level (level 2) is useful at providing general guidance, through the influence of the OM existing at level 1 (Ex.: explicitly modifying the local view of an entity, like the set of corresponding entities to dialog with), in order to attain a global objective; otherwise the low decisional level might have an uncontrolled emergent behaviour. The high decisional level is represented here by the coordinator holon which besides general guidance offers a mean of integrating the fabrication system into the upper layers of the factory (Ex.: attaching client demands to order holons, supervision of the system, computing parameters describing the global behaviour of the system, etc).

Although an FMS is composed of transportation, processing and storage resources, for fabricating a product only the processing resources are mandatory; the others are just used to automate the transportation process. For this reason when executing a product the decisional module should provide an answer to the following questions: What is the next operation? What is the resource that will do that operation? How do I bring the product there?

The last two questions are being considered together in order to minimize the sum of the processing and routing times. According to Fig.3 the general order execution process is composed of the following three subprocesses: - First, an order (seen as an active decisional product) *updates its personal knowledge* about the possibilities of each resource from the system (A); - Second, a *decision* that regards the three questions posed above is taken (operation, **R**esource for **P**rocessing (RP), **R**esource for **R**outing (RR)) (B); - and third step, *execution* (C) takes place.

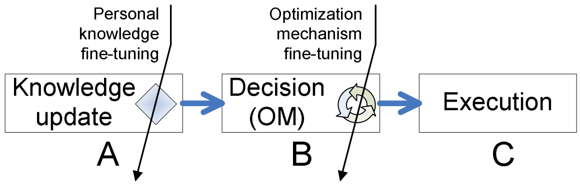

Fig.3 General order execution process

The extended process is a modified version of the Contract Net Protocol (FIPA, 2002) and is described in Fig.4.

Fig.4 represents the dynamic interaction of the decisional entities presented in Fig.2 for optimizing the allocation and execution operations. The choice for the product to be manufactured is done by the augmentation module in a fixed location, the input/output of the system. Once a product is chosen it cannot be changed unless its production was completed or it was damaged in the manufacturing process. In order to find out what type of product should be attached to the pallet, the augmentation module should interrogate the client's orders database, then the system resources and then, according to the products deadlines, to their complexities and also to the charge of the system a single product representing a production order is chosen for fabrication.

The interaction process between an OH and the RHs, representing the dialog arrow in Fig 2, begins with the "Knowledge update" stage during which each operation of the order (op_k, k=1:total_number_of_operations) is tested to see if there is a corresponding resource capable of executing it. Then, for each resource found capable of executing a processing operation a path towards it is searched (For each RP{op_k}). The knowledge update process takes place two times, the information exchanged and the way it is exchanged being almost the same except that it is done for different type of resources: update the processing model and update of the routing model.

The updating model process relies on the exchange of information between entities using messaging mechanism. The messages to resources are sent in the form of call for proposals (*cfPp* referring to calls made for processing resources and *cfRp* referring to calls made for routing resources) and because the dialogue is synchronous, in order not to block an order waiting for a response from a failed resource, timeouts for replies are imposed:

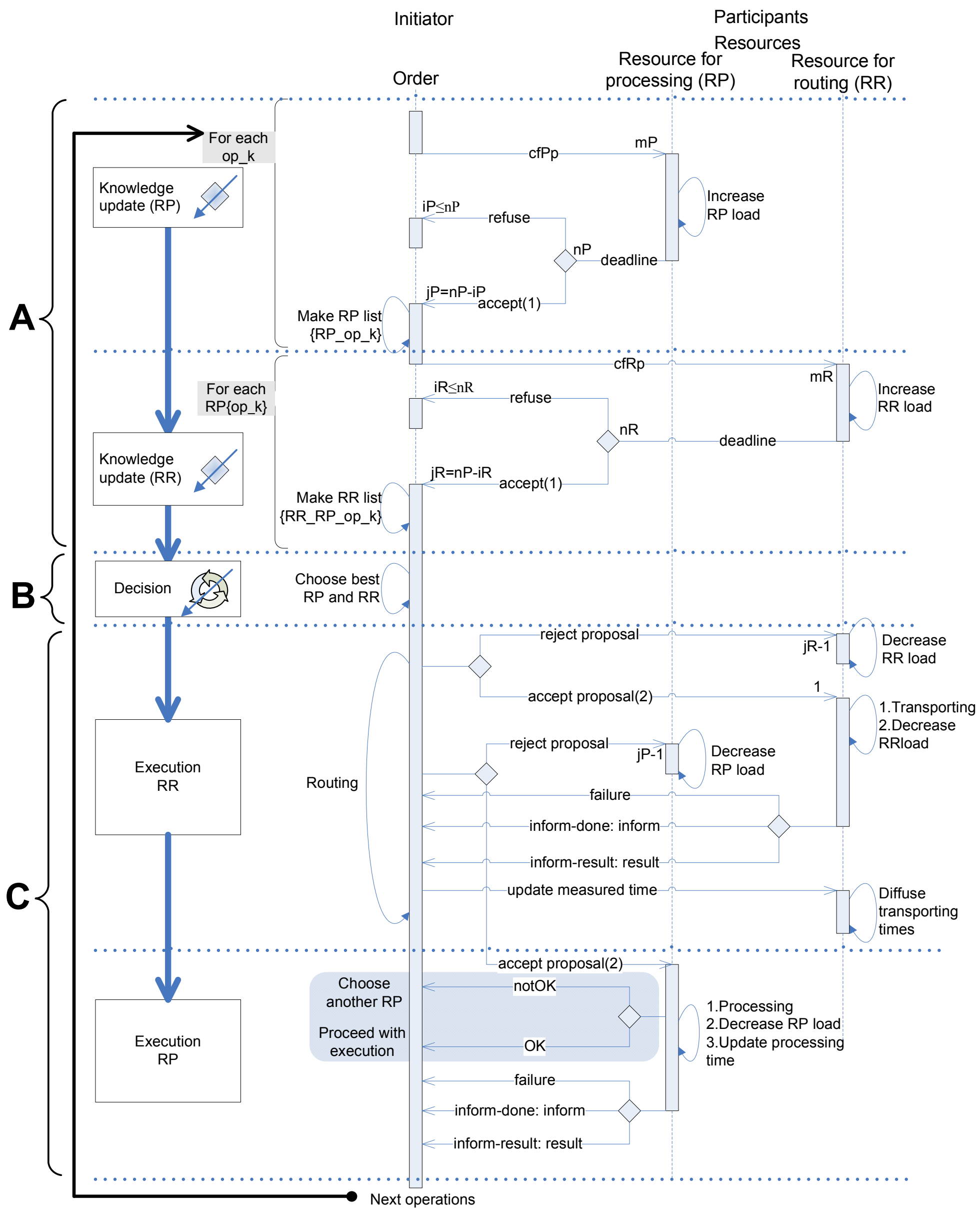

Fig.4 Interactions between order holons and resource holons for optimizing the allocation and execution operations

if the resource does not respond in the established interval it is declared off-line and it is not taken into account during the decision making process. If the resource replies in this interval the answer can be negative or positive. The negative answer represented by the *refuse* arrow in Fig.4 indicates that the state of the resource does not permit to execute the requested operations because the resource is busy with other products, or the resource can not execute the requested operations; in both cases the resource is operational. The positive response is represented by the *accept* arrow that indicates the availability of the resource to execute the requested operation.

After the "knowledge update" process the model of the system is ready and the production order can begin taking decisions which regard the manufacturing process: what is the next operation, on what resource it's done and what is the path to the resource.

After the above decisions are taken, the workloads of the chosen routing and processing resources are increased. This process is represented on the diagram of the interactions in negative logic (to respect the standard Contract Net Protocol (FIPA, 2002)), with the aid of the *proposal reject* message which is sent to all the resources that have participated in the dialogue and have not been chosen; in order not to increase and then decrease resource charge during each dialogue it was chosen to increase only once the charge, after the decision, when the chain of resources is finally chosen.

In Fig.4 is shown the case where only a single production order interacts with the resources of the manufacturing system. In the real case there are several products, the resources being able to face all of them.

The start of an operation, routing or processing, is marked by the *accept proposal* message, which in the case of processing resources may contain additional parameters (e.g.: the points between which an assembly operation is done). Before the production order enters the processing resource a last dialog takes place between it and the corresponding resource in order to confirm the production possibility. After the *accept proposal (2)* message, the chosen resource must send a message that contains either *OK*, the product can enter, or *notOK*, the resource has failed during the routing phase of the production order or another product is in production or there is no raw materials in the workplace, in which case the product jumps at the decision state, seeking another answer to the 3 questions from above.

The end of an operation is marked by the reception of one of the following messages *inform-done, inform-result or failure*. *Inform-done* is a simple message sent if the resource has well finished the operation. If more information is required then the resource can send a detailed message of the execution, *inform-result*. *Failure* is a simple message sent by the resource to inform that the requested operation has failed (e.g.: the video inspection has not found the requested characteristics of the object).

For other production orders to take into account the transportation times in real-time (e.g.: instantaneous charge of a line between two resources) travel times are measured and then written to the destination transport resource with the aid of *update measured time* message; this time is then diffused to all the other transport resources via a broadcast mechanism.

The optimization mechanism (OM) is done using the dialogue between the entities of the system. The information exchanged in order to minimize the makespan is the charge of each resource.

4. Experimental results and perspectives

The open-control concept presented above is currently under deployment at the Flexible Manufacturing System at AIP PRIMECA Valenciennes, Fig.5, composed of a multi-path conveyor, self-propelled pallets with embedded decision capabilities, and flexible workstations with industrial robots and visual inspection cameras.

The transporting resources are composed of the underlying infrastructure on which the order holons move, along with the control represented by WAGO PLCs (Wago, 2009) that drive the transfer gates according to the commands received from the OH. The processing resources are represented by the corresponding resources and the PLCs that do the control, and consist of industrial robots.

The interactions between resources and orders (Fig.6) take place in special places and via an Ethernet-IrDA bridge which aids to both communication and localisation. In our case the bridges consist of IrDa Clarinet systems ESB 101 (Clarinet system, 2009) located for the transporting resources before the transfer gates and for the processing resources in the station workplace.

The practical results achieved till now, *dynamic routing* and *resource allocation*, were conducted on a small scale model of a real FMS, more precisely the TARGET AREA zone in Fig.5, and were satisfactory in terms of correctness of operations and stability of the system in face of disturbances such as perturbations jams on the transportation infrastructure.

The implementation of the routing part from the general interaction scheme from Fig.4 to the small scale model was done as depicted in Fig.6 making use of the MODBUS protocol which already exists on the PLC controlling the resources. On the down side we have the entities that participate at the dialogue, the order holons and the resource holons,

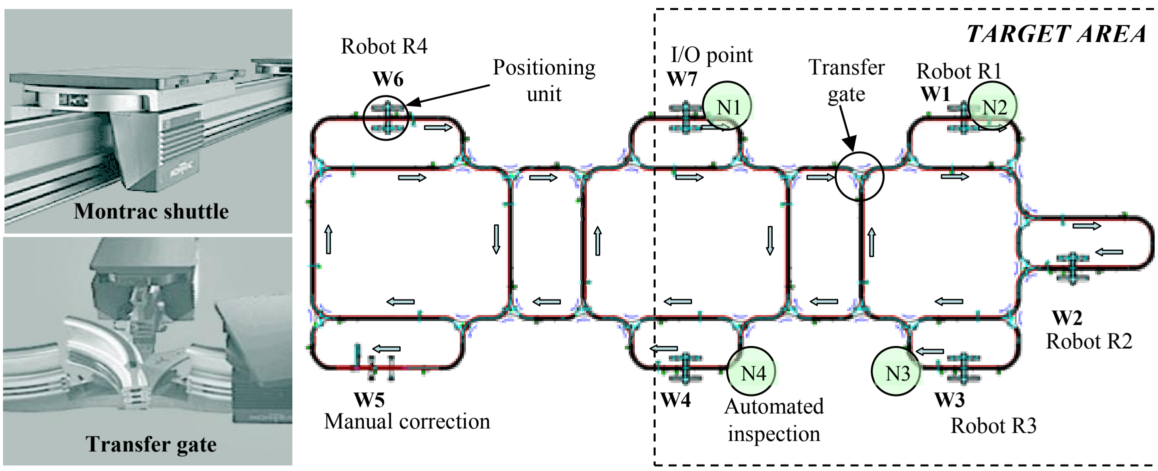

Fig.5 AIP cell system layout

and in the upper part an adaptation of the general dialogue, routing and allocation, in Fig.4 is presented.

Before starting execution, or after finishing an operation the online allocation of the next operation takes place as depicted in Fig.6. Afterwards, the routing towards the selected resource is done.

When the Order Holon arrives at a routing node, the following messages are exchanged after connection for the routing purpose:

- The OH transmits the measured time it took to travel from the previous node to the current one and the RH broadcasts it to the others RH updating in real-time the routing information;
- Information about the current resource is read from its control PLC;
- The transportation times are sent to the OH, which updates its routing model and chooses the best neighbor by applying locally by the OH the Dijkstra routing algorithm, work detailed in Zbib et al, 2008;
- The OH sends a routing demand to the current RH which acts upon the transfer gate.

The next steps to cover are the implementation of the routing procedure and the online allocation procedure on the real FMS from Fig.5 and then do a comparison between a static (offline) allocation and the online allocation using the societal open-control concept and holonical approach.

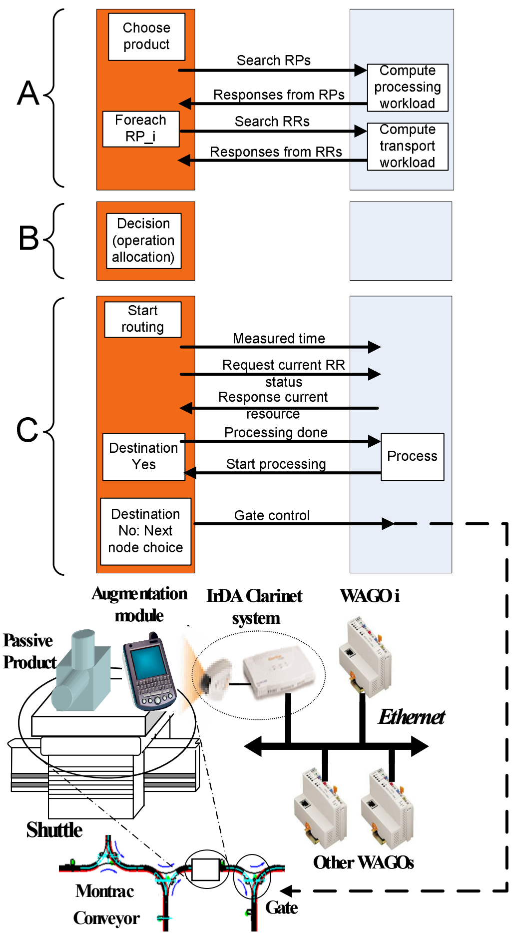

Fig.6 System architecture and order-resource interactions for routing and allocation

5. Conclusions

In this paper we have presented the societal open-control, a control paradigm well suited for decentralised FMS, which combines the advantages of "classical" control architectures, the possibility of hierarchical systems to achieve a global optimum, and the reactivity and easy maintenance, due to easy removal and addition of composing elements, of heterarchical systems. All these advantages come at a certain price in terms of extensive work and programming knowledge needed which is nevertheless justified if the designed fabrication system aims at an increased productivity and great flexibility.

Also, in this paper we tried to show that the open-control concept, and especially the implicit societal part, works very well into a holonic manufacturing system, since the proposed dialog between entities is key element of the holonic theory.

6. References

Borangiu, T., Ivanescu, N.,Raileanu, S., Rosu, A., Vision-Guided Part Feeding in a Holonic Manufacturing System with Networked Robots, RAAD 2008, Ancona, Italy

Bousbia, S. and Trentesaux, D. Self-Organization in Distributed Manufacturing Control: state-of-the-art andfuture trends. In proc. of IEEE SMC'02, Tunisia, 2002

Clarinet System, Network Connectivity for Mobile Devices, http://www.clarinetsys.com, 2009

Dorigo, M., and Stützle, T. Ant Colony optimization. The MIT Press, 2004

Dijkstra E W, ''A note on two problems in connexion with graphs''. Nu-merische Mathematik, 1:269,271., 1959

FIPA, 2002, FIPA Contract Net Interaction Specification, www.fipa.org, consulted in February 2009

Koestler, A. The Ghost in the Machine. Hutchinson publishing Group, London, 1967

Maione, G., and Naso, D. A soft computing approach for task contracting in multi-agent manufacturing control. Computers in Industry, 52, 199–219, 2003

Nylund H., Kai Salminen, Paul H Andersson, A multidimensional approach to digital manufacturing systems, 5th International Conference on Digital Enterprise Technology Nantes, France 2008

Okino, N. Bionic Manufacturing System in Flexible Manufacturing System: past – present – future. J. Peklenik (ed), CIRP, Paris, 73-95, 1993

Raileanu, S., Sallez, Y., Berger, T., Borangiu, T., Trentesaux, D., Holonic implementation of the open-control paradigm, IESM' 2009, May 13 - 15, 2009 Montreal, Canada

Sallez Y., Berger T., Trentesaux D., Open-control: a new paradigm for integrated product-driven manufacturing Control,13th IFAC Symposium on Information Control Problems in Manufacturing (INCOM '09), Russia, June 3-5, 2009

Sauer O., Automated engineering of manufacturing execution systems – a contribution to "adaptivity" in manufacturing companies, 5th International Conference on Digital Enterprise Technology Nantes, France 2008

Trentesaux, D. Les systèmes de pilotage hétérarchiques : innovations réelles ou modèles stériles ?. Journal Européen des Systèmes Automatisés, 41 (9-10), 1165-1202, 2007

Trentesaux, D., Dindeleux, R. and Tahon, C. A MultiCriteria Decision Support System for Dynamic task Allocation in a Distributed Production Activity Control Structure. Computer Integrated Manufacturing, 11 (1), 3-17, 1998

Van Brussel, H., Wyns, J., Valckenaers, P., Bongaerts, L. and Peeters, L. Reference architecture for holonic manufacturing systems: PROSA. Computers in Industry, 37 (3), 255–274, 1998

Wago system, innovative connections, http://www.wago.com, 2009

Zbib, N., Raileanu, S., Sallez, Y., Berger, T. and Trentesaux, D. From Passive Products to Intelligent Products: the Augmentation Module Concept. 5th International Conference on Digital Enterprise Technology, Nantes, France, 2008