Using of Distributed Intelligent Agents for Holonic Control of Adaptive Manufacturing Systems

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Abstract: - The paper presents some considerations and a concept regarding on using of distributed intelligent agents in holonic control of adaptive manufacturing systems perspective. Unlike the classical manufacturing control systems, holonic manufacturing control systems provide a high agility and adaptability to the environment changes, and robustness against the occurrence of disturbances, bringing the advantages of modularity, decentralization, autonomy and scalability. Nowaday, holonic architectures combine the Function Block based programming, for the low-level real-time control, and the Multiagent technologies, for the decision-making level. This new distributed control concept allow the manufacturing systems reconfiguring for the their adapting at the variable environment.

Key-Words: - Distributed control, Holonic manufacturing systems, Biological manufacturing systems, Fractal manufacturing systems, Virtual cellular manufacturing, Intelligent Multiagent, Reconfigurable systems.

1 Introduction

The area of industrial production in the last decades and at present, too faces a series of changes determined by the passing from a local economy to a global one, the orientation of market demands towards high quality products and of reduced costs, the efforts made by the companies to fulfill as much as possible the customers’ requests, producing goods with the particular character and, generally, having a reduced living cycle. On the other hand, the rapid and continuous evolution of the technology often determines the adaptation and integration of the existing systems in new systems having an advanced control architecture reducing obsolescence from the technological point of view.

The traditional systems of production are in some wise rigid, offering a weak answer to changes due to the rigidity and the centralized architecture of the control system. Under these circumstances, the development of control systems is required implying industrial processes characterized by autonomy, intelligence, adaptability to changes, being at the same time, robust in presence of perturbations.

In order to completion of there requirements, more solutions were suggested regarding to the manufacture systems realizing, among which the most well-known are: biological manufacturing systems (BMS) [1]; holonic manufacturing systems (HMS) [2]; fractal manufacturing systems (FMS) [3] and virtual cellular manufacturing (VCM) [4]. Some of them are briefly presented as following: the holonic concept; the holonic architectures; intelligent agents concept and their usage in holonic manufacturing systems; reconfiguration of these manufacturing systems.

2 Holonic Manufacturing Systems and Architectures

2.1 Holonic concept

The holonic concept was defined by the Hungarian writer and philosopher Arthur Koestler who suggested the term holon to be used for describing a base organizing unit in biological and social systems [5]. Two important characteristics of the holon make it an adequate instrument modeling used in designing both manufacturing systems and materials manipulation systems. First of all, the independence offers the holons the right to take decisions without consulting a superior entity. Secondly, the cooperation enable the holons the right to take decisions without consulting a superior entity. Secondly, the cooperation enable the holons to communicate with others holons, too, in order to develop planning mutual accepted sequences and their execution.

The applicability of the such concepts in manufacturing systems was mentioned for the first time by Suda [6]. His observations led to the creation of HMS project in 1993 with a feasibility study proper before the first phase of the project. The HMS project [2] was developed in the IMS (Intelligent Manufacturing Systems) program [7]. The concept of the IMS program was described in Japan in 1988...
and represents an international initiative for the research and development of the following generation of technology rules in manufacturing systems [8]. The HMS program is one of the first and most vast project of the IMS programs involving over 50 organizations in Canada, USA, Europe, Japan and Australia.

The application of holone concepts in manufacturing systems leads to a new approach of the problems in the industrial field, due to the advantages brought by them: modularity, decentralization, autonomy and scalability.

2.2 Holonic architectures

2.2.1 PROSA architecture

PROSA (Product Resource Order Staff Architecture) [9] was defined as a holonic reference architecture for the manufacturing systems developed by a group of researchers from the Catholic University in Leuven, Belgium. In this architecture the holons are used to represent the products, resources, commands and logical activities. This architecture defines three main types of holons: product holons; resource holons and order holons as follows in Fig. 1.

A resource holon is compound by a physical part representing one of the physical resources of the manufacturing system and an information processing part having the role to control the respective resource. This type of holon contains models for allocating the existing resources, as well as organizing knowledge, functioning and control of the resources in order to obtain the final product. A resource holon is an abstraction of a production means, for example, a factory, a workshop, machines, ovens, conveyers, component parts, materials, tools, holding tools devices, human operators etc.

Product holons include the knowledge about the process and product, necessary to assure the correct fulfillment of the product having an acceptable quality. A product holon contains substantial information about the product life, the customer’s requirements, design fulfillment the bill of materials (BOM), quality insurance procedures etc. acting as a server of information for the other holons in the manufacturing system.

A command holon represents a task in the production system, being responsible for the correct and on time fulfillment of the associated activities. A command holon can represent the customers’ commands, for maintenance and repairing the resources etc. The fulfilled tasks are traditionally associated with those of a dispatcher of a monitor of the progress and of a short terms planner.

Besides these basic types of holons, a series of staff holons are mentioned, for example, the scheduler, which are meant to assist and council the basic holons. They analyze different aspects of the basic holons problems offering information in order to help taking the best decisions in solving the problems. The responsibility in taking the decision is for the basic holon, the staff colon being considered an external expert which gives some pieces of advice.

This architecture combines the robustness and predictability of the hierarchical control with the rapid reaction to disturbances due to the hetero-hierarchic control.

2.2.2 ADACOR architecture

ADACOR (ADAptive holonic COntrol aRchitecture) for distributed manufacturing systems (DMS) is a holonic architecture for the distributed manufacturing systems proposed by Paulo Leitão [10].

The ADACOR architecture is meant to have a control structure as decentralized as possible and at the same time centralized because it is necessary to assure the global perfection of the system. It is based on a set of independent and cooperative entities represented by the holons which enable a distribution of the abilities and knowledge and assures the improvement of the adaptation capacity to the environmental changes. Each holon is the representation of a component part of the manufacturing process which can be either a physical resource (numerically commanded machines – CNC, robots, programmable controllers, pallets etc), or a logical entity (commands, product).

The holons which create the architecture are grouped in the following classes: the product holons (ProdH), the tasks holons (TH), the operational holons (OpH) and supervisor holons (SuPH), as can by noticed in Fig. 2, too.

![Fig. 1. Main holons in the PROSA architecture](image-url)
The *supervisor holons* are inspired from the biological systems and present characteristics which are different in comparison with the *staff holons* defined in the PROSA reference architecture. They represent an innovating aspect of the proposed architecture and were created in order to introduce a coordination and a global optimization in the decentralized control solutions. A supervising holon can coordinate some operational holons or other supervisor holons.

**Fig. 2. Holon Classes of AD ACOR architecture [10]**

An *operational holon* may consist of a series of operational holons or supervisor holons, which enables the building of *fractal holanhies*, as is presented in Fig. 3.

**Fig. 3. Fractal organization in ADACOR architecture approach**

The holons in ADACOR architecture are based on the *plug and produce* principle, a new element can be added in the system without the reinitializing or reprogramming of the system, which leads to higher flexibility in reconfiguration the system. When a holon enters the system, it announces and offers its services to the other holons. When it leaves the system, the remaining holons must be able to find alternative solutions in order to replace the missing information produced by the which left the system.

According to the paper [10], the improvements brought by introducing the ADACOR architecture can be noticed on two different levels: the design level and the operational level.

At the *design level*, taking into consideration the advantage of using decentralized systems, the design, the maintenance, the expanding and the reutilization of the applications in the manufacturing control is more simply accomplished than in the case of traditional solutions. At the *operational level*, the proposed architecture offers an adapting mechanism of the manufacturing control system structure in the case of the disturbances appearance and coming back to the normal operation after the disturbance disappearance. In this way, the optimization of the centralized control, in the absence of disturbances, is combined with the agility of the hetero-hierarchic control in unstable situations determined by the frequent appearance of deferent disturbances.
The designing and modeling of the holonic architectures use different methods and instruments. For static description can be used UML instrument and for dynamic description are used Petri Nets and the fractal theory.

3 Using of Intelligent Agents in Holonic Systems

In large meaning, an agent represents a computational system situated in an execution medium where it is able to make autonomous actions for performing purpose objectives.

An intelligent agent represents a hardware-software system that has the following main properties: autonomy; reactivity; pro-activity; social ability.

The concept of Multi-Agent Systems (MAS) evolves from that of distributed control. Durfee et al [11] defines MAS as “a loosely coupled network of problem solvers that work together to solve problems that are beyond their individual capabilities”. Research in MAS considers the behavior of a group of autonomous agents aiming to solve a given problem. MAS is a component of artificial intelligence, concrete of Distributed Artificial Intelligence (DAI).

The fundamental focus of the MAS is to instill methods for the creation of highly distributed control agents. The negotiation of agents is supported by fast auto-determination decision process. Auto-determination of agents corresponds to the degree of autonomy an agent has to build, commit, and carry out an action plan.

This behavior operates well in response-critical environments, where the intelligent agents expect synchronous responses, as opposed to pure MAS where asynchronous communication is the core mechanism. In this work, the agents operate in both domains, asynchronous and synchronous. The MAS architecture is organized according to the following characteristics:

- Autonomy: Each intelligent agent makes its own decisions and is responsible for carrying out its decisions toward successful completion;
- Cooperation: Intelligent agents combine their capabilities into collaboration groups (clusters) to adapt and respond to diverse events and mission goals;
- Communication: Intelligent agents share a common language for cooperation;
- Fault tolerance: Intelligent agents possess the capability to detect equipment failures and to isolate failures from propagating;
- Pro-action: Intelligent agents periodically or asynchronously propose strategies to enhance the system performance or to prevent the system from harmful states.

Agent planning is carried out in three main phases: Creation, Commitment, and Execution. During creation, an intelligent agent initiates a collaborative decision making process (e.g., a load that will soon overheat will request cold water from the cooling service). The intelligent agents offer a solution for a specific part of the request. Then, the intelligent agents commit their resources to achieve the task in the future. Finally, the intelligent agents carry out the execution of the plans.

Figure 4 shows an example for one intelligent agent architecture. There are four main components:

- Planner, that is the brain of the intelligent agent and its reasons about plans and events emerging from the physical domain;
- Equipment Model, that is a decision-making support system; the Planner evaluates configurations using models of the physical domain;
- Execution Control, that acts as a control proxy and translates committed plans into execution control actions and it also monitors events from the control logic and translates them into response-context events to be processed by the Planner component;
- Diagnostics, that monitors the health of the physical device. It is programmed with a model of the physical device, where a set of input parameters is evaluated according to a model to validate the readings.

![Fig. 4. Example for an intelligent agent architecture](image-url)
generic architecture for the holonics control devices, called *HCD Architecture* [12]. This architecture has two levels: a deliberative level represented by a high level agent software component and a physical level compound by sensors and acting devices. This last level is real time constrained conditions. The communications between these two levels are realized by a special functional block called *control functions layer*. A holon defined in this mode embed together, in a single structure, the technologies with intelligent agents and the classic control applications. These types of agents are called *holonic agents*.

According to [13], three communication channels can be identified in this architecture:

- *intra-holon* communication between low level control component and high level component represented by agent;
- *inter-holon* communication that executes the sending messages between the holons;
- *direct*, communication between components that executes the holons real time control.

For inter-holon communication is used, usually, FIPA (Foundation for Intelligent Physical Agents) [14] standardization and direct communication is achieved by others standards, like IEC 61499 [15], that achieve support for real time restrictions.

### 4 Reconfiguration of Holonic Manufacturing Systems

*The reconfiguration system* refers to its possibility to answer to any changes by the available resources reorganization, thus that the system performance will remain the same or can be very little affected.

In order to satisfy the new provocations in the manufacture modern systems was introduced the reconfigurable system concept. Such a system can be integrated in a new manufacture type in a very short time by using hardware and software modules. The reconfiguration allows the adding, ruling-out or modifying of a specific manufacturing units, of the control, of the software or the machine structure modifying for an optimal adapting to the requested market.

The system reconfiguration quality involves the following characteristics:

- *modularity* for the hardware and software components;
- *integrability* (the designing of the system and of the components for rapid integration and for the new technologies introducing);
- *diagnosability* (the rapid identification capacity of the quality problems and the system defaulting);
- *personalization* (the system design for adapting at the manufacturing of a product by adequate hardware and software components).

The reconfiguration of a distributed system can be approached on three complexity levels [16]: simple; dynamic and intelligent.

*The simple reconfiguration* involve the usage of a model as IEC 61499 [15] for the problems avoidance by the reason of the software coupling, the problems that can appear in the time of the reconfiguration system.

*The dynamic reconfiguration* uses techniques for the software optimal synchronization in the reconfiguration time.

*The intelligent reconfiguration* uses multi agents techniques for to allow the automatic reconfiguration system, as the answer of the appeared changes.

In paper [16] is presented a reconfiguration model for a holonic system, at the real time level control. In the purposed model (Fig. 5), the ports of the functional blocks (the connections for data and events) are connected to a resources manager that memorizes all ports.

![Fig. 5. Reconfiguration Model ([16] adapted)](image-url)

The IEC 61499 model defines a resource as an entity compounded by more interconnected functional blocks and a device as an entity compounded by more resources. In consequence, the relation between resources and devices is like the relation between the functional blocks and resources. In this manner, *the drives manager* makes the connections between the resources ports stored in the *Ports Table* (MR). In similar manner, *the applications manager* makes the connections between devices manager ports, storing adequate information in the *Ports Table* (MD).
Using this model, a devices manager, for example, can realize the reconfiguring of the resources managers ports that are connected to it in order to be in correspondence with any new desired configuration. The presented solution advantage consists in fact that the reconfiguration can be realized at the different levels (at the functional blocks, resources, devices, applications), the only single thing needed being a map of new configuration interconnections.

Other approach of the manufacture systems reconfiguration problem is presented in the paper [17]. This approach, uses the manufacture virtual cells concept pursuant the manufacture virtual cells systems performances increasing. This concept involves the system performances analysis and the available resources reshuffling in virtual cells, if necessary, every time when a new production order must be introduced. The goal of virtual cells forming is the performance characteristic factors minimizing or maximizing. These characteristic factors are: the interact between cells, the system delays average, the system using average and the product capacity average. For the interact between cells an analytical equation is used and the values for other three performance indicators are determined by a simulation/scheduling special module.

An important reconfiguring aspect is the Plug and Produce concept presented in the paper [18]. This is similar to Plug and Play concept used for the computer devices, but it refer to the easier adding or removing of the distributed system component devices by automatic update of system information’s. In this manner, the reconfigurable costs are very much reduced. The Plug and Produce concept, together with a non-centralized architecture, lead to a higher flexibility level for the manufacture systems.

4 Conclusion
The Holonic Manufacturing System (HMS) is a research initiative to develop next generation of adaptive manufacturing system. The based component of HMS is the holon.

A holon is defined as an autonomous and cooperative building block of a manufacturing system for transforming, transporting, storing and/or validating information and physical objects. The holon is structured in two levels: a high level represented by an agent and a low physical level.

The agent is an autonomous component, that represents physical or logical objects in the system, capable to act in order to achieve its goals, and being able to interact with other agents, when it doesn’t possess knowledge and skills to reach alone its objectives.

References: