Multi-agent and manufacturing- A multilevel point of view

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Abstract

The increasing demand for flexibility has led to new manufacturing control paradigms based on the concept of self-organization and on the notion of agents. But there is a lack of methodologies in the design of agent oriented manufacturing systems. We explore the design of such systems at three different levels of the manufacturing process: workshop, cell and machine-tool level, emphasize the specificity of each level and outline possible solutions.

At the workshop level, the heterogeneity of the system leads to agent identification problems. We present a model of an autonomous agent that facilitates the identification. For an efficient man-machine integration, we propose a self-organizing protocol that benefits both from the initiative of the human spirit and the efficiency of the artificial machines.

The complete automation of the cell level allows for the use of scheduling techniques, but short term disturbances and the complexity of the problem led to a very fast but low efficient self-organizing protocols. We propose a variation of the contract-net that uses genetic algorithms.

Finally, long term changes in production is the specificity at the machine tool level. A formal method to describe both the machine and the control system in terms of reliability is outlined. It enables the designer to choose a composition of the agent system that reduces communication and optimizes the total reliability.

Keywords

Bionic, contract net, CIM, design, FMC, FMS, heterarchic, HMS, machine tool, multi-agent, reliability, self-organization, workshop.

1 INTRODUCTION

The first manufacturing control architectures were usually centralized or hierarchical. The poor performance of these structures in very dynamic environments (Duffie, 1987) and their difficulties with unforeseen modifications (Dilts, 1991) led to new control architectures. **Multi-agent** paradigms emerged like Multi-Agent (Ferber, 1995), Holonic Manufacturing (Christensen, 1994), Heterarchical (Hatvany, 1985) and Bionic (Okino, 1993) Systems. They all present a relevant interest to the manufacturing community because they bring a solution to the management of the uncertainty of the manufacturing environment.

The different Multi-agent paradigms have a common feature. They all propose **Self-Organized Systems** that change their internal organization on their own account. The aim of this paper not being to differentiate the various paradigms, we will use **Multi-agent** as a generic term for **self-organized**.

Therefore, a multi-agent manufacturing system is composed of self-organizing agents, that may be completely informational (i.e., order or scheduling agents) or representing subsystems of the physical world.

We propose a basic decomposition of the design of multi-agent oriented manufacturing systems :

1. Identification of the agents.
2. Design of the self-organizing protocol.

In these two steps of the design we propose to identify some specificity and guidelines tied to the three following levels of the manufacturing process:

- Workshop level that represents the usual factory workshop, with a mix of CNC and traditional machine tools, human operators, robots, etc. .
- Cell level that corresponds to a completely automated manufacturing system, that can act with a minimum interference of the operators.
- Machine tool level where the different components of the system are completely integrated in the same platform.

2 DESIGN OF A MULTI-AGENT WORKSHOP

Workshops are usually heterogeneous: Not only are the material resources different in function and nature but they belong to different organizations (human organization, automated control). This heterogeneity of the system makes the identification of the agents rather unclear.

Our agent identification method proposition (Schäfer, 1996) is based on the idea that an agent should be an **autonomous intelligent operator** (Morel, 1994) to improve the system fault tolerance capabilities (Duffie, 1994). We can thus deduce the agent basic capacities:

- to transform its environment in at least one of the dimensions shape, space and time.
- to control the result through observation
- to communicate to palliate its lack of observation capacity.

The resulting model for our manufacturing agent is shown in Figure 1, and an application for a specific workshop is given in Table 1.

Figure 1 The Manufacturing Agent Model.

Table 1 Sample Workshop Composition

	<i>Transformation</i>	<i>How to observe?</i>	<i>How to act?</i>
Resource Agent	Form	camera or human operator	to use machining or assembling tools
Part Agent	Time	electronic tag	to cause resource utilization
Storage Agent	Time	human operator	to store and distribute in the stockage area
Transport Agent	Space	camera, sensor or human operator	to effect delivery with AGV or human operators

However, what distinguishes the workshop level from the cell level is the human operator. To integrate the operator in the automated system, a solution consists in interfacing an agent with him (Christensen, 1994). Inter-agent organization is then taken in charge by the artificial agents and the human being is simply considered as a resource.

We claim that the operators could participate directly in a self-organizing process at the same level with the artificial agents. This could be realized with **reactive** agents (Ferber, 1995), that have simple behaviors based on their perceptions. Although individually very simple, a reactive multi-agent system may exhibit very

complex group behavior. An example for the transport of the parts mixing human and auto-guided vehicle could be made with a simple system of lamps:

When a workstation needs a transport agent it sends a red light that signals its need. Artificial agents controlling the AGV detect the signal, and if they have no task to do, they automatically approach the source. The human transport operator can also see the signals. He may participate in the transport process or not depending on his own judgment of the situation.

In this section we have shown the specific heterogeneity of the workshop, outlined a model for agent identification and presented a self-organization protocol adapted to human integration in such a system.

3 THE FLEXIBLE MANUFACTURING CELL

The specificity of the Flexible Manufacturing Cell (FMC) is to be completely automated. In that case there is no basic contrast to the agent identification in the workshop. Figure 2 presents the composition of our generic system with the OOA formalism (Coad, 1991). There are only two types of agents: the stations and the transfer system. Parts and storage area are not considered as agents because they have no resources enabling them to be autonomous (Ramos, 1997).

Complete automation allows the use of traditional scheduling methods. But in the case of job-shop manufacturing, the problem is both dynamic and NP-hard. The scheduling is then confronted with a combinatorial explosion of the number of solutions with a very limited search time. Multi-agent specific scheduling techniques have already been employed to solve job-shop problems. Among them the contract net protocol (Smith, 1981) was used in several manufacturing systems (Parunak, 1988), (Duffie, 1987). This self-organizing protocol was found to give low efficient scheduling (Nof, 1994). The challenge is now to increase the system performance. Dividing the problem in two and using a combination with a traditional scheduling method may bring a solution.

The internal problem of the Workstation

The workstation has several Parts to machine and must find a schedule optimizing an internal criteria. For this problem the Genetic Algorithm (GA) approach was used (Aizana, 1994).

The problem of the allocation of Parts to the Workstation

The contract net approach is applied here : The arrival of a part to the FMC is transmitted to the transfer agent that must find a workstation for it. An offer is broadcast to the stations with the message "location" which activates their own GA. The workstation then sends the message to the transfer agent "acceptpart" which contains the proposal of acceptance at a specific date. The transfer agent chooses the workstation and transports the part with a minimum processing date. This dynamic is shown in Figure 2.

Figure 2 Composition and dynamic of the cell

We have modeled a FMC with one transfer and five machine agents. The internal criterion of the workstation is the minimization of the staying time of the parts (Cmax) on the machine. The parts arrival ratio at the FMC is 0,3 1/min and processing times are random. Figure 3 shows a global criterion of FMC, the average number of jobs still to be completed by time t.

Figure 3 Evolution of a the average number of jobs to be completed

In this section we have stressed the automation of the FMC and its dynamic job-shop scheduling problem, outlined a possible solution combining GA and the contract net.

4 MULTI-AGENT MACHINE TOOL

The specificity of multi-agent design for a machine tool lies in the adaptation to important changes in production rather than short term disturbances. A possible solution is to lower the size of the agents in the system and increase their number.

For example, a robot, composed of a gripper and two NC axis, can be controlled with one agent (the robot), or with three (the gripper and the two axis).

But increasing the number of agents led to a loss in communication bandwidth and in time (Ferber, 1995). For example in a system composed of N agents using the contract net self-organizing protocol, the number of the messages is going to be in $o(N^2)$. So a limitation in the agents number may be compulsory. And due to the non-autonomy of the machine tools agent, this is not obvious at all. We propose a method to value the different solutions, based on the reliability analysis of the system and on the dependencies between agents.

For a machine tool S composed of n agents A_i and m material components C_j , where the agent A_i controls the k_i components $\{C_{(i-1)k_i+1}, \dots, C_{ik_i}\}$.

c_i represents the state of the component C_i : $c_i=1$ if the component is functional and $c_i=0$ if the component is out of order.

a_i represents the state of A_i : $a_i=1$ if the agent is alive and $a_i=0$ if the agent is dead. The mathematical formulation of a_i is then,

$$a_i = \left(\prod_{j=(i-1).k_i}^{j=i.k_i} c_j \right) \cdot \Phi_i(a_1, \dots, a_n) = \left(\prod_{j=(i-1).k_i}^{j=i.k_i} c_j \right) \cdot \Phi_i(a) . \quad (1)$$

Where the function Φ_i is the structural function that expresses the relationship between the agents of the system and agent A_i . If Φ_S is the structure function of the system, the global reliability R of the system is then,

$$R = P(\Phi_S(a_1, \dots, a_n) = 1) . \quad (2)$$

R has a maximum value when each agent controls only one component. We can now give our design principle concerning non-autonomous agents :

- The number of agents should be maximum to increase long term flexibility.
- The maximum number of agents is given by the limitation of the communication network and the self-organizing protocol used.
- In case of communication overhead, agents could control more than one material component.
- The ideal regrouping is a regrouping whose reliability tends to the maximum reliability that the machine components can give.

The reliability of the different agent composition is calculated with formula (1) and (2).

Figure 4 Shiva

Figure 5 Production for different machine configurations

An application of this design proposal was made with the machine tool Shiva. This double milling machine has redundant transport and machining capacities. Our agent design procedure showed that an agent controlling the three axis module, the spindle and gripper associated, implies a satisfactory minimum decrease from the maximum reliability.

This multi-agent control system was successfully tested on several simulated machine configurations (Figure 5). It showed that the control system could adapt itself easily to a new production.

5 CONCLUSION

We have outlined design identification methods for different levels of the manufacturing system and shown their specificity :

- man-machine integration and heterogeneity at the workshop level
- short term disturbances in an automated environment at the cell level
- long term changes in production at the machine tool level

Applications of these principles have been presented and all of them offer benefits in integration, efficiency, flexibility and reliability in partially unknown manufacturing situations.

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