Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 21
ISSUE 1
March
2007

Survey of the agent-based approach to intelligent manufacturing

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Received 07.11.2006; accepted in revised form 15.11.2006

Analysis and modelling

ABSTRACT

Purpose: Summary of the state-of-the-art of the Distributed Artificial Intelligence applied to Intelligent Manufacturing. Main applications are presented along with different technologies applied in these areas.
Design/methodology/approach: Intelligent Manufacturing area was split into many segments, which require different approach to intelligent problem solving. Multiagent systems negotiation needs were analysed and cooperation issues in the form of clustering, cloning, and learning were analysed in search for the relevant tools.
Findings: Detailed review of the approach to development of the agent based Intelligent Manufacturing from the fundamental considerations to the latest hands-on developments.
Research limitations/implications: Many presented technologies call for detailed study before they can be implemented in practice.
Originality/value: Thorough review of the Distributed Artificial Intelligence approach to current agile manufacturing needs. Key technologies are pointed out along with the main areas in which they can be implemented, and which require further research.
Keywords: Artificial intelligence method; Intelligent manufacturing; Multiagent systems; Holonic manufacturing systems

1. Introduction

Manufacturing strategies have currently to face global competitiveness, big number of new products, and be suited to rapid market responsiveness. The enterprises will be in an environment with changing markets, introducing new technologies, and competitors from all over the world. The manufacturing systems will have to be time-oriented, while taking into account cost and quality, having to meet the following requirements: Interoperability, Fault Tolerance, Cooperation, Scalability, Enterprise Integration, Distributed Organization, Heterogeneous Environments, Open and Dynamic Structure, Agility, Integration of humans with software and hardware. Techniques from Artificial Intelligence (AI) are mentioned which are in use in Intelligent Manufacturing for more than 25 years [1-3].

There are yet new achievements in agent-based systems constituting the new domain of Distributed Artificial Intelligence (DAI). The agent-based technology has been employed to carrying a number of tasks including, but not limited to production planning, scheduling and execution control, enterprise integration and supply chain management, as well as materials handling and inventory management [4-6].

Operation of the Intelligent Manufacturing systems calls for various agent architectures, in which three types of agents are used. Type A agents, which represent the physical system entities, like a workpiece, a machine or production line/cell, humans, the shop floor subsystem, or the entire plant in a supply chain, part-oriented scheduling, and even the whole scheduling process; Type B agents created on the fly by the Type A agents group to resolve a scheduling conflict; and finally the Type C agent, as a high-level supervisory entity focused the overall manufacturing goals. In

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general all system elements - agents - function in a layered architecture; using different mechanisms at different levels. The agents used include the functional agents, usually designed using the BDI approach, employing the voting protocol for communication and Contract Net negotiation protocol to reach final decisions and complete task allocation problems [7-15].

The meanings of agent and autonomy which are used in this paper, are described by the following definition, modified in comparison to [2]: "an agent is an intelligent system situated in some environment, and that is capable of autonomous action in this environment in order to meet its design objectives." Therefore, an autonomous agent is expected to be able to act without the intervention of humans and can choose if it needs to act in cooperation with other agents, having control over its own actions and internal state.

The natural consequence has been the next step - the holonic manufacturing in which the system intelligence is spread among certain entities, called holons being autonomous, cooperative and to some extent intelligent. In holonic manufacturing systems, agents are used to model holons which are software and hardware entities. A holon can be part of another holon. In this, more general approach, each organisation unit can be considered as a holon, which can collaborate with other holons. Intelligent agents called 'holons' have a physical part as well as a software part. This idea of dynamic and decentralized manufacturing process assumes that humans may be effectively integrated within its framework. This attitude, unlike distributed systems, causes that the individual entities in holonic manufacturing environment cooperate in ad-hoc hierarchies to reach a global goal [16-20].

2. Enterprise Integration and Supply Chain Management

The notion of the Enterprise Integration means that each entity of the system has access to the information it needs, according to its task and understands how its actions would impact other system entities. Therefore, such entities can choose alternative actions which may lead to optimizing the system goals. The Supply Chain [] of a manufacturing system is its network of suppliers, factories, stores, and retailers using which the input materials and elements are acquired, processed and made available to end-users as final products. Agent-based technology is the obvious method to develop and implement such environment. Moreover, it has been applied during the past fifteen years also to inventory management, manufacturing planning, scheduling, execution control and materials handling.

Manufacturing control is an important area of agent based system applications for operating a manufacturing plant. These systems take into account the observed plant states - both the present and past observed ones, as well as the changing market demand. The control problem has to be solved at low- and high-levels. The low-level control layer is focused on the individual manufacturing process resources featuring the unit-processes required by the high-level control functions. On the other hand the high-level manufacturing control coordinates the manufacturing resources to produce the required product mix. Agent technology is usually applied to high-level manufacturing control. In the Autonomous Agent Systems concept the focus is on the coordination and negotiation among intelligent autonomous agents. When several agents can execute the same tasks or operations, a negotiation mechanism is used to set up relationships between a seller agent and a buyer agent. Usually the manufacturing cell subcontracts work to other cells using a bidding mechanism based on Contract Net protocol, as each factory and its component is an agent with a collection of plans based on its capabilities. This protocol carries out the dynamic assignment of operations to the system resources to fulfill the tasks. The re-negotiation phase may be needed when any exceptions appear.

Table 1.
Areas of agent technology applications

Application	Technology
Enterprise Integration	Service agents (Name Server, Facilitator Agent, Gateway Agent)
	Large number of computerized assistants, known as Intelligent Agents (IAs)
Supply Chain Management	Agent Building Shell (ABS); Coordination Language (COOL); functional agents
	Using mobile agents to an industrial process
Agile Manufacturing	Using the Internet
	An agent defined as an autonomous, encapsulated software component
	Supply chain library with structural elements (agents) and control elements for coordination
Intelligent Manufacturing	A rule based object system for developing intelligent manufacturing software
	Dynamic clustering & cloning; learning
CIM Systems	Database agents for CIM systems
Virtual Enterprise	Using mobile agents
Project Management	Using mobile agents

Basic models simulate the performance of coordination structures present in a many different systems from the computer systems to the human organizations. The autonomy of the agents yields the systems capable to react to disturbances; however, a certain degree of hierarchical control still allows global optimization of the entire agent system. Agent based approach provides a convenient way to model and implement manufacturing enterprise integration and supply chain management set up as a network of cooperating, intelligent agents. Each agent carries out one or more supply chain functions while coordinating its activity with other agents. There are two types of function groups carried out by agents fulfilling the supply chain functions: control elements and the structural ones. Control elements include demand, supply, inventory, flow and information controls to coordinate flow of products. Structural elements include production elements like suppliers, plants, distribution centres, retailers, and transportation elements which can be represented as agents (Table 1).

3. Multiagent System Architectures

The architectures proposed in the literature for agent-based manufacturing systems fall into three approaches: the Hierarchical approach, the Federation one, and the Autonomous Agent one. Any modern manufacturing enterprise is composed of many, most often distributed physically, semi-autonomous units, all having a certain degree of control over local resources or having varying information requirements. In such real situations, a certain number of agent-based industrial applications still use the hierarchical architecture.

As regards federation architectures, the following approaches have been used: Facilitators, Brokers and Mediators. Facilitators are several related agents which are combined into a group. A facilitator is a communication interface between agents. Every facilitator is responsible for ensuring communication between a local collection of agents and remote agents, by: routing outgoing messages to their destinations, translating incoming messages for its agents.

Brokers resemble the facilitators having two additional functions such as monitoring and notification. The difference between a facilitator and a broker is that a facilitator is responsible only for a given group of agents, whereas any agent may contact any broker in the same system for finding service agents to complete a special task.

In addition to the functions of a facilitator and a broker, a mediator assumes the role of system coordinator by promoting cooperation among intelligent agents and learning from the agents' behavior. The Federation multi-agent architectures can to coordinate multiagent activity via facilitation as a means of reducing overheads, ensuring stability, and providing scalability.

The Autonomous Agent approach is different. The autonomous agent should have the following characteristics at least: it is not controlled or managed by any other software agents or human beings; it can communicate/interact directly with any other agents in the system and also with other external systems; it has knowledge about other agents and its environment; it has its own goals and an associated set of motivations. The Autonomous Agent approach is well suited for developing distributed intelligent design systems where the system consists of a small number of agents and for developing autonomous multiple robotic systems.

4. Agent Development Tools

Development of the agent-based manufacturing systems was usually carried out so far using such programming languages like C++, Java, Lisp, Prolog, Objective C and SmallTalk. However, efficient agent development tools are urgently needed (Table 2).

Table 2.
Exemplary agent development tools

Tool name	Developer	Application
ABS (Agent Building Shell)	EIL of the University of Toronto	developing cooperative enterprise agents
		developing multi-agent applications in the area of manufacturing enterprise supply chain integration
ObjectSpace's Voyager™		for mobile agents
ZEUS	British Telecom	for engineering distributed multi-agent systems
ADE (Agent Development Environment)	Gensym	intelligent manufacturing software development environment
		development of agent-based systems for supply chain management
Aglets SDK	IBM	general agent development tool
ADT (Agent Development Toolkit)	SRI	general agent development tool

Efforts have been made to set forth standards for agent-based systems, however there are no accepted standards for developing agent based manufacturing systems. Only a few projects can be named, like KQML intended to be a common communication language for agents, or KIF being a common content format. The Foundation for Intelligent Physical Agents (FIPA) promotes the development of specifications of generic agent technologies that maximize interoperability within and across agent-based applications.

5. Conclusions

There are two different approaches to agent design: the physical decomposition approach and the functional decomposition one. In the physical decomposition approach, agents represent physical entities, like workers, machine tools, tools, fixtures, or products, etc. On the other hand, in the functional decomposition approach, there is no relationship between agents and physical entities, but agents are assigned to some functions like product distribution, , transport management, order acquisition, scheduling, material handling, etc. Development of multiagent systems requires taking into account the specific features of these two abovementioned approaches. The functional approach is characteristic of sharing many state variables across different functions, i.e. agents, which may lead to some unexpected interactions and their behaviour inconsistency. The physical approach, however, defines separate sets of state variables managed by individual agents thus limiting their interactions. An important security problem exists because of the open architecture of agent based systems. Organisations all over the world have to support nowadays their competitiveness global on a global scale and have to acquire the rapid market responsiveness. To achieve it all every manufacturing enterprise has to be integrated with its management systems (i.e., design, orders, scheduling, purchasing, production control, transport, personnel, materials, etc.). They do it cooperating with their partners and customers via local networks, the Internet or Intranet. This is a serious issue when using the mobile agent technology and the Internet.

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