A review paper on Multi agent base intelligent manufacturing system

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Abstract— *Today, hot topic for researchers is intelligent manufacturing system and its new paradigms to face the problems and challenges of the 21st century's manufacturing industry. A new approach with this new paradigms is problem solving through decomposition and agent base solution is seen as one of the promising in responding to the needs of next generation manufacturing system. Researchers have attempted to apply multi-agent base technology to achieve autonomy, decentralization, flexibility, reliability, efficiency, learning, and self regeneration characteristics in manufacturing system. This paper provides a review on the recent achievements in these areas, and discusses some key issues in implementing agent-based intelligent manufacturing systems such as IMS structure, concept of MAS and its architecture, application domains, advantages, challenges, agent development tools and migration to MAS.*

Keywords— multi-agent system (MAS), intelligent manufacturing system (IMS), distributed manufacturing systems (DMS), flexible manufacturing systems (FMS).

I. INTRODUCTION

In the last three decades manufacture concepts have had several redefinitions, in the eighties, the concept of flexible manufacturing systems (FMS) was introduced to develop a new family of products with similar dimensions and constraints but nowadays, the capacity of reconfiguration has become a major issue for improving the functioning of industrial processes. Indeed, today a main objective is to adapt quickly in order to start a new production or to react in a failure occurrence [1]. Intelligent manufacturing systems has both °flexibility and reconfigurability, in fact this concept brings more than a few ideas of software intelligence meanings, which contemplates characteristics such as autonomy, decentralization, flexibility, reliability, efficiency, learning, and self regeneration, all of these facilities lead to the concept of agent-based manufacturing systems.

The current challenge is to develop collaborative and reconfigurable manufacturing control systems that support efficiently small batches, product diversity, high quality and low costs, by introducing innovative characteristics of adaptation, agility and modularization. Information and communication technologies, and artificial intelligence techniques, have been used for more than three decades to addressing this challenge. The Multi-Agent system (MAS) theory in distributed artificial intelligence (DAI) provides feasible technical support for modeling and realization of intelligent manufacturing system (IMS). Manufacturing process is a typical Multi-Agent questions solution process, and every department (or segment) in manufacturing system is equal to an Agent in the process. Every sub-mission or unit equipment in manufacturing system could be acted and realized by single Agent or well-organized Agent group, and complete the manufacturing tasks together through their interaction and mutual coordination and cooperation. The manufacturing system shall be stimulated as the MAS, which makes the system easier to design, reduces the complexity of the system, intensifies the recombination, expandability and reliability of the system, and improves the flexibility, adaptability and dexterity of the system.

In this paper, intelligent manufacturing based on multi agent system presented. The objective is to give a general idea of the complexity of the future manufacturing systems, The organization of this paper is as follows, Section II explain the Structure of intelligent IMS. Section III reviews the concept of software agent, MAS and its architecture. Section IV gives application domain and control system of MAS in IMS. Section V shows the advantages and challenges of the MAS. Section VI explains methodology to migration from traditional to MAS. Section VII deal with agent development tools and Section VIII presents the paper conclusions.

II. THE STRUCTURE OF IMS

Intelligent Manufacturing is a man machine integrated intelligent system composed by intelligent machine and human experts, which can carry out intelligent activities such as analysis, inference, decision-making, conception and judgment during the process of manufacturing. The cooperation between intelligent machine and human will expand, extend and partially replace the work of human experts during the process of manufacturing [4]. At the same time, it will collect, store, perfect, share, inherit and

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develop the manufacturing intelligence of human experts [5].

The main types of IMS are: IMS that takes improving manufacturing system intelligence as the object and intelligent robot and Agent as the tool; IMS that integrates the modeling, processing, measuring and operating of corporations through Internet; biological IMS that adopts solution procedure for biological problems. At present, the distributed network IMS model based on Agent is mainly adopted [6], the architecture of which is illustrated in Figure 1. On the one hand, each manufacturing unit is endowed autonomy by Agent to become the entity with perfect functions and autonomy independence; on the other hand, the system is endowed with self organization capacity through the coordination and cooperation between Agents.

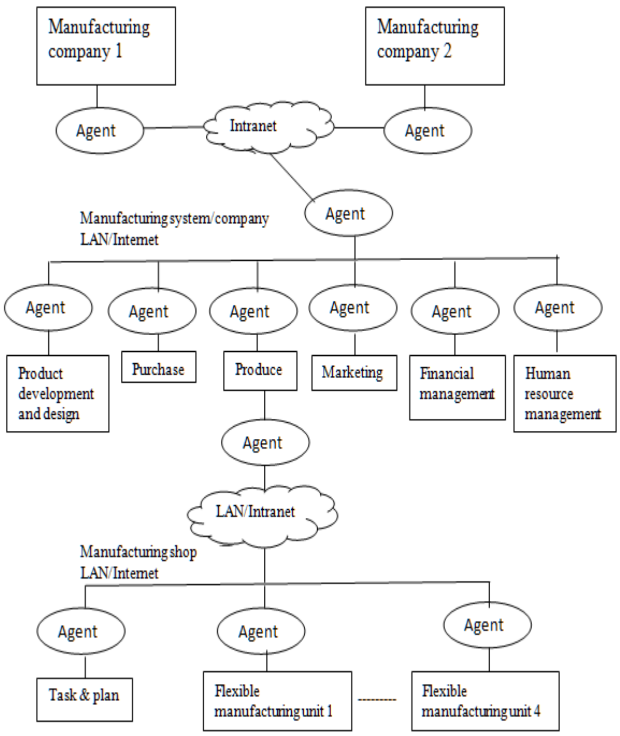

Figure 1. Network model block graph [23]

When IMS integrates the intelligent machine and human on production site, it flexibly centralizes all activities such as order, design, produce and sales of the company through knowledge base, database, computers and communication network in order to improve the overall efficiency. The segments of order, design, produce and sales are functional independent from each other, and their solution procedures are quite different. The functional subsystems of each segment independently complete manufacturing sub-tasks as well as coordinate with each other. Therefore, inside the manufacturing company, the whole manufacturing process from design to sale is a typical solution procedure for Multi-Agent questions.

In order to improve the adaptability of manufacturing system to the state changes from inside to outside, the general structure design of IMS shall obey the open principles, which are showed as: (1) openness of the task: the task could be input and processed at any time; (2) openness of the system: the system shall hold the changes from interior system, and accept the interference from outside; (3)openness of solution procedure: the solution procedure shall accept the changes of information and knowledge. In order to realize the openness of these three aspects, distributed structure is resorted to in the IMS, which endows every component entity and subsystem of the system with larger autonomy to form the intelligent autonomous agent [23]. Intelligent autonomous agent is connected with computer communication network by means of intelligent nodes, which are equal in logic dispersive in physic and independent in function. The nodes have the loosely coupled relations [7], which contact each other by transferring messages. Based on the common communication language, they coordinate and cooperate to complete the manufacturing tasks.

III. AGENT AND MULTI-AGENT SYSTEMS

3.1 Agent

An agent is a real or virtual entity able to act on itself and on surrounding world, generally populated by other agents. Its behavior is based on its observation, knowledge and interaction with the world of other agents. An agent has capabilities of perception and partial representation of the environment, can communicate with other agents, can reproduce child agents, and have own objectives and autonomous behavior.

According to Jennings and Wooldridge's [12] ''an agent is a computer system situated in some environment, and that is capable of autonomous action in this environment in order to meet its design objectives.'' Under the context IMS, we can define an agent as a software system that communicates and cooperates with other software systems to solve a complex problem that is beyond of the capability of each individual software system. An autonomous agent should be able to act without the direct intervention of human beings or other agents, and should have control over its own actions and internal states.

An agent operates in an environment from which it is clearly separated (Figure 2). Hence, an agent (1) makes observations about its environment, (2) has its own knowledge and beliefs about its environment, (3) has preferences regarding the states of the environment, and finally, (4) initiates and executes actions to change the environment. Agents operate typically in environments that are only partly known, observable and predictable. Autonomous agents have the opportunity and ability to make decisions of their own. Rational agents act in the manner most appropriate for the situation at hand and do the best they can do for themselves. Hence, they maximize their expected utility given their own local goals and knowledge. The most important common properties of computational agents are as follows:

- Agents act on behalf of their designer or the user they represent in order to meet a particular purpose.
- Agents are autonomous in the sense that they control both their internal state and behavior in the environment.
- Agents exhibit some kind of intelligence, from applying fixed rules to reasoning, planning and learning capabilities.
- Agents interact with their environment, and in a community, with other agents.
- Agents are ideally adaptive, i.e., capable of tailoring their behavior to the changes of the environment without the intervention of their designer.

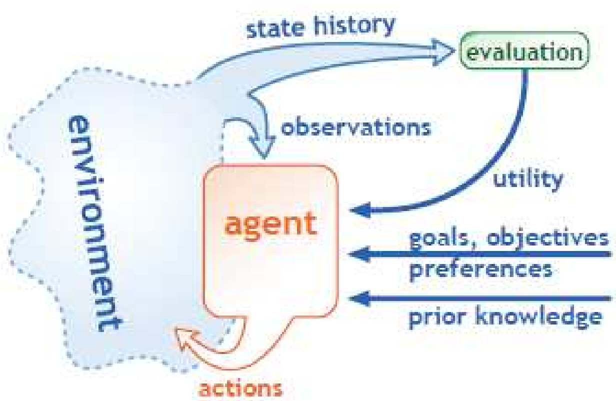

Figure 2. The agent and its environment [13].

3.2 Multi-agent systems

A multi-agent system (MAS) means a system in which the key abstraction used is that of an agent. It is a loosely coupled network of problem solvers that work together to solve problems that are beyond their individual capabilities. The agents may have only a partial model of their environment and may possess a limited set of means for the acquisition and integration of new knowledge into their models and for pushing the system's state towards their own goals. The knowledge of two agents, referring to the same things, is not necessarily commensurate and may have different representations. No closed-system assumption has to be maintained: the MAS is submerged into and interacts with its environment, which is not described completely by formal means. Whenever novel kinds of interaction with the environment may occur, the MAS should be open and able to evolve.

In a community an agent has to coordinate its actions with those of the other agents; i.e., to take the effects of other agents' actions into account when deciding what to do. Coordination models provide both media (such as channels, blackboards, pheromones, market, etc.) and rules for managing the interactions and dependencies of agents. Coordination requires some regulated flow of information between the agent and its surrounding environment, in other words, communication. Note that in a MAS coordination is possible both by indirect communication via the environment, or by direct information exchange between specific agents. In any case, communication needs some languages with syntax and semantics, at least partially known for each communicating agent.

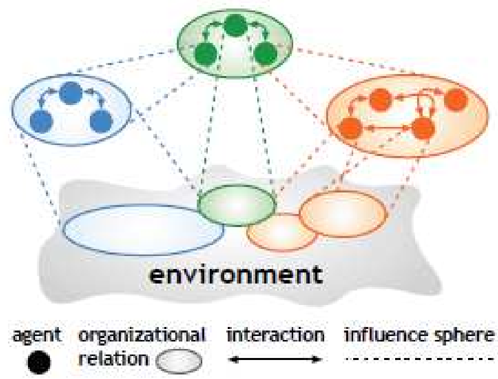

Figure 3. Generic scheme of MAS [14].

Collaboration means carrying out concerted activities so as to achieve some shared goals. For instance, in a scheduling domain machine agents may agree on executing each task of a job with the aim of completing an order by the given due date. The shared goal (completing an order) can be achieved only if all agents commit themselves to carrying out the actions they have agreed upon. In general, meeting high-level objectives and satisfying system-wide constraints need cooperation in a multi agent system where agents are self-interested and autonomous.

The overall operation of MAS is affected by an organization that is imposed on the individual agents. Even though there may be no global control or centralized data and the computations are asynchronous, some organizational rules always exist. The organization determines the “sphere” of the activity of agents, as well as their potential interactions (see Figure 3).

3.3 MAS 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 [22]. 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 multi agent 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.

IV. APPLICATION DOMAINS AND CONTROL SYSTEM OF MAS

Techniques from Artificial Intelligence have already been used in Intelligent Manufacturing for more than two decades. However, the recent developments in multi-agent systems have brought new and interesting possibilities. Therefore, researchers have been trying to apply agent technology different domain of IMS like, manufacturing enterprise integration, enterprise collaboration, manufacturing process planning, scheduling and shop floor control, materials handling and inventory management. Figure 4 illustrate comparison between Conventional vs. Multi-agent manufacturing control system. Some important application domains of agents in MAS are described below [20], [21]:

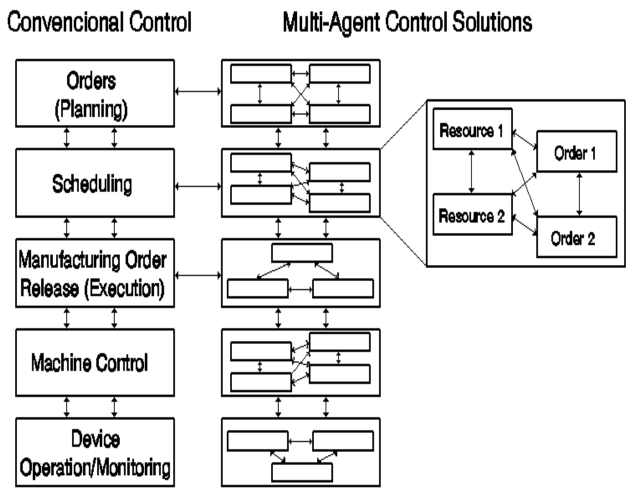

Figure 4. Conventional vs. Multi-agent manufacturing control system [17]

- Order agent, represents an order to be accomplished by the production system.
- Process planning agent, plan of the several processing phases to produce a work piece of an order.
- Process scheduling agent, minimize the production time and costs from process planning.
- Coordinator and Supervisor agent coordinate and supervise the actions between different agents imposing the correct execution of the rules established in the system.
- Resource agents, have the responsibility of manage different resources. For example work piece agent manages the processing state of the work piece, the

transport agent decides autonomously in which direction a work piece is forwarded inside the production system, and the machine agent, controls the machine.

V. ADVANTAGES AND CHALLENGES OF MULTI AGENT SYSTEMS

5.1 Advantages:

There are many advantages [18] [19], provided by the characteristics of MAS related to:

1. Technological and application needs: Multi agent system offer a promising and innovative way to understand, manage, and use distributed, large-scale, dynamic, open, and heterogeneous compounding system.
2. Natural view of intelligent systems: Intelligent and interaction are deeply and inevitably coupled, and multi agent systems reflect this insight. Natural intelligent systems, like human, do not function in isolation; they interact in various ways and at various levels. MAS provide insight and understanding about poorly understood interaction among natural, intelligent beings, as they organize themselves into various groups, committees, societies, and economies in order to achieve improvement.
3. Complexity management: There are 4 major techniques for dealing with size and complexity of enterprise information systems; modularity, distribution, abstraction, intelligence. The use of intelligent, distributed agents combine all four techniques
4. Speed-up and efficiency: Agents can operate asynchronously and in parallel, and this can result in an increased overall.
5. Robustness and reliability: The failure of one or several agents does not necessarily make the overall system useless, because other agents already available in the system may take over their part.
6. Scalability and flexibility: The system can be adopted to an increased problem size by adding new agents, and this does not necessarily affect the operationality of other agents.
7. Costs: It may be much more cost-effective than a centralized system, since it could be composed of simple subsystems of low unit cost.
8. Development and reusability: Individual agents can be developed separately by specialists, the overall system can be tested and maintained more easily, and it may be possible to reconfigure and reuse agents in different application scenario.
9. Privacy: A centralized approach is not possible sometimes because system and data may belong to companies that for competitive reasons want to keep them private.

5.2 Challenges:

Although the advantages discuss above, there are still challenging questions to be answered such as [19],

1. How to enable agents to decompose their goals and tasks, to allocate sub goals and sub tasks to other agents, and to synthesize partial results and solutions?
2. How to enable agents to communicate? What type of communication languages and protocols to use?
3. How to enable agents to represent and reason about the actions, plans, and knowledge of other agents in order to appropriately interact with them?
4. How to enable agents to recognize and reconcile disparate viewpoints and conflicts? How to synthesize views and results?
5. How to engineer and constraint practical multi agent system? How to design technology platforms and development methodologies for manufacturing system?
6. How to effectively balance local computation and communication?
7. How to enable agents to negotiate and contract? What negotiation and contract protocols should they used?
8. How to enable agents to form and dissolve organizational structures?
9. How to formally describe multi agent systems and the interaction among agents? How to make sure that they correctly specified?
10. How to realize ‘intelligent processes’ such as problem solving, planning, decision making, and learning in multi agent contexts? How to enable agents to collectively carry out such processes in a coherent way?

VI. THE METHODOLOGY OF MIGRATION TO MAS

Since multi-agent technology has been recognized as a key concept in building a new generation of highly distributed, intelligent, self-organizing and robust manufacturing system, the traditional concept of manufacturing systems has become vulnerable to changes [9]. Environmental changes, failure detection, reconfigurability, and expandability; are a set of capabilities that make an attractive option migration from traditional to MAS. The migration should be such that it is easier to adopt new production infrastructures without dramatic hardware changes and long setup times. Presently, there are several topologies of manufacturing cells, such as centralized, hierarchical, and heterarchical structures [10]. Each of this topology could be considered as optimal and able to accept migration, taking into account that each element should be related without complete dependency and well functioning shall not be compromised with any other element from the cell, after migration is implemented. A generic platform was designed in order to apply MAS. The platform design was implemented in such a way that any °flexible manufacturing cell could be evolved into agent-based structure. The clue is to adopt the platform structure, and shape each element (robots, numeric control machinery, conveyors) of a cell to acquire agent personality. Once the problem or problems are identified the MAS design phase, starts, which is more oriented toward the implementation of the generic platform; however a methodology should be committed.

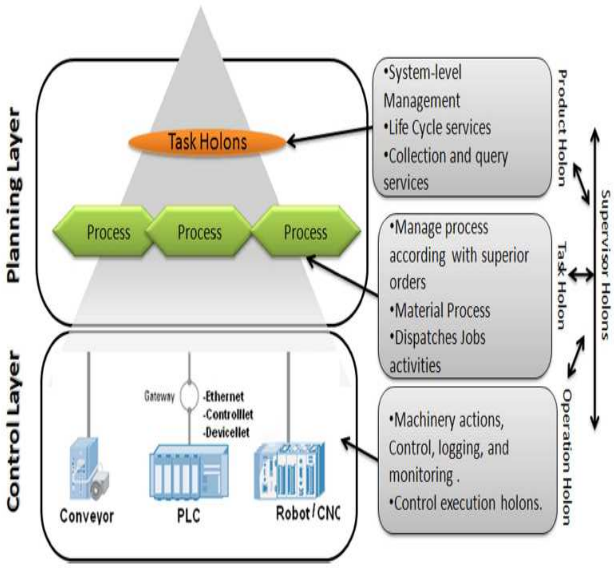

Figure 5. Hierarchy model of communication and interaction[11]

Figure 5 shows how agents can be integrated and how data would be interchanged, wherein the three layers, that computer system in manufacturing management use, are illustrated. The generic plat-form is toward from general to particular application, so before start working on developing intelligence, is crucial to make independent each element, which is supposed to emerge from a centralized and sequential architecture that actually shall be substituted by the new platform. The superior part of this pyramid is performed by management layer, which are satisfied with a manufacturing planning level, and a manufacturing execution level. Both could be programmable holons, purely software based. In addition pyramid bottom is formed by executable holons, which has direct contact with machinery, and hardware systems, also this part of the pyramid frequently is the one with more constraints in manufacturing environments. The efforts on this section will be driven to get the pyramid base prepared to be adapted without neither hardware changes nor design, on the other hand ready to become reconfigurable, and holonic-ready [9], the methodology as shown in figure 6 shall be describe in four steps[11].

1. Define Communication Structure
2. Isolate from global system
3. Convert from general to particular
4. Create relationships but not dependences

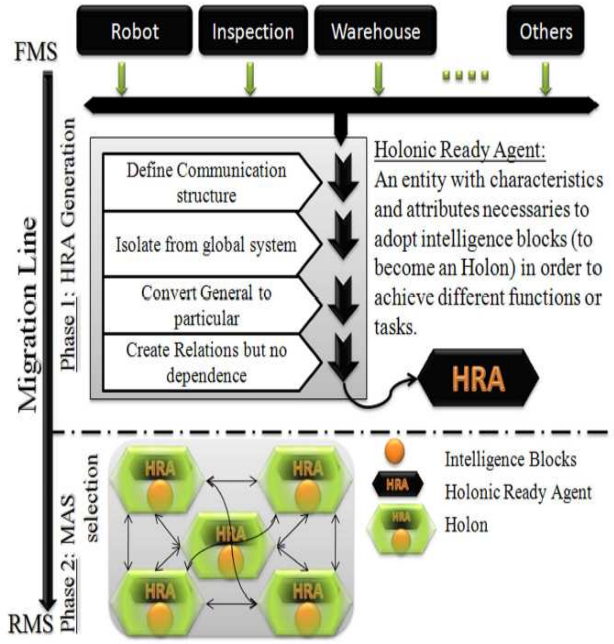

Figure 6. The methodology model implemented to achieve migration feature [11]

The result after this methodology would be what we call a "holonic-ready agent", which meaning contemplates an entity with characteristics and attributes necessaries to adopt intelligence blocks (to become a Holon) in order to achieve deferent functions or tasks. An over-all view of the resulting platform is shown in a more oriented way the methodology applied on the commercial software used to develop the generic platform. The methodology makes reconfigurability possible into the manufacturing cell.

VII. AGENTS DEVELOPMENTS 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).

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 [22].

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 VoyagerTM		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

Table 1. Exemplary agent development tools [22]

VIII. CONCLUSION

MAS make the manufacturing system easier to design, reduce the complexity, intensify the recombination, expandability and reliability of the system, and improve the flexibility, adaptability and dexterity of the system. It can offer distributed intelligent control actions to create evolvable systems required on the flexible and distributed manufacturing systems already needed in ours days and essential for the future. This paper presents the review on multi agent base intelligent manifesting system and dealt with structure, architecture, application domains, advantages, challenges, migration to MAS and agent development tools.The main characteristics to implement IMS based on autonomous agents are presented and concept and use of MAS is explained.

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