Intelligent agents applied to manufacturing: the MAKE-IT approach

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Abstract

We present the state of art in agent technology applied to manufacturing and our MAKE-IT architecture. In our approach, a manufacturing agent is based on a knowledge model, implemented in Clips. Each agent is able to dialogue with other agents, with Relational DataBase Management Systems and with Real Time Manufacturing Database Systems in XML, tunneling the dialogue in a Microsoft Message Queue (MSMQ) channel. This architecture aims to fill the information gap between the shop floor level and the business information system, linking production to e-commerce, in a solution that is particularly interesting for small medium manufacturing enterprises.

1. Introduction

We can classify the period we are living as software revolution. In the last years we have seen a remarkable increment of software technologies, and in particular technologies as Internet where the information is highly distributed. The growth of information sources on the Web has caused many web users to suffer from information overload. Software agents aim to resolve this kind of problems and others. They are probably the fastest growing area of information technology. The agents are being used for application as personalized information management, electronic commerce, and management of complex commercial and industrial processes, in particular workflow management. Many definitions were given about agents. Patti Maes has given a general definition of agent as: a computational system which is long-lived, has goals, sensor and effectors, decides autonomously which actions to take in the current situation to maximize progress towards its (time-varying) goals [1].

Our current research focuses on the application of agent technology to workflow management, in particular in manufacturing enterprises. Many definitions have been assigned to workflow. Among these, the Workflow Management Coalition [2] has defined workflow management as the computerized facilitation or automation of a business process in whole or part.

After a wide introduction to the state of art and to the application of agent technology in manufacturing with special reference to workflow management, we introduce our approach to agent technology in manufacturing.

2. Information and knowledge management in manufacturing

Manufacturing is one of the main fields of application of agent technology. In fact, Artificial Intelligence techniques have been widely used in the so-called Intelligent Manufacturing for more than twenty years. However, the recent developments in multi-agents system in the new domain of Distributed Artificial Intelligence have brought new and interesting possibilities.

Global competition and rapidly changing customer requirements are forcing major changes in the production styles and configuration of manufacturing organizations. Traditional centralized and sequential manufacturing planning, are being found insufficiently flexible to respond to changing production styles and highly dynamic variations in product requirements. The traditional approaches limit the expandability and reconfiguration capabilities of manufacturing systems. Agent technology provides a natural way to overcome this kind of problems, and to design and implement distributed intelligent manufacturing environments. The agent technology gives also to the product system a better fault tolerance. Recently, agent technology has been considered an important approach for developing industrial distributed systems. The manufacturing enterprise is rapidly changing and it is likely to work in environments where markets are frequently shifting, new technologies are continuously emerging, and competitors are multiply globally. The main fundamental requirements that a manufacturing information system (MIS) will need to satisfy are [3]:

<u>Enterprise integration.</u> In order to support global competitiveness and rapid market responsiveness, an individual or collective manufacturing enterprise will have to be integrated with its related management systems and its partners via networks.

Distributed organization. For effective enterprise integration across distributed organizations, distributed knowledge-based systems will be needed so as to link demand management directly to resource and capacity planning and scheduling.

Interoperability. Heterogeneous information environments may use different programming languages, represent data with different representation languages and models, and operate in different computing platforms. The sub-systems and components in such heterogeneous environments should interoperate in an efficient manner. Translation and other capabilities will be needed to enable such interoperation or interaction.

Open and dynamic structure. It must be possible to dynamically integrate new subsystems into or remove existing subsystems from the system without stopping and reinitializing the working environment. This will require open and dynamic system architecture.

Cooperation. Manufacturing enterprises will have to fully cooperate with their suppliers, partners, and customers for material supply, parts fabrication, final product commercialization, and so on. Such cooperation should be in an efficient and quick-response manner.

Integration of humans with software and hardware. People and computers need to be integrated to work collectively at various stages of the product development and even the whole product life cycle, with rapid access to required knowledge and information. Heterogeneous sources of information must be integrated to support these needs and to enhance the decision capabilities of the system. Bi-directional communication environments are required to allow effective, quick communication between human and computers to facilitate their interaction.

Agility. Considerable attention must be given to reducing product cycle time to be able to respond to customer desires more quickly. Agile manufacturing is the ability to adapt quickly in a manufacturing environment of continuous and unanticipated change and thus is a key component in manufacturing strategies for global competition. To achieve agility, manufacturing facilities must be able to rapidly reconfigure and interact with heterogeneous systems and partners. Ideally, partners are contracted with "on the fly" only for the time required completing specific tasks.

Scalability. Scalability means that additional resources can be incorporated into the organization as required. This capability should be available at any working node in the system and at any level within the nodes. Expansion of resources should be possible without disrupting organizational links previously established.

Fault tolerance. The system should be fault tolerant both at the system level and at the subsystem level so as to detect and recover from system failures at any level and minimize their impacts on the working environment.

Just in time (JIT) production. Performances in manufacturing production could certainly be improved by an appropriate management of operational information. Decisions relevant to the planning of the activities involved in manufacturing production should rely on information about the status of the processes, from supply to production and distribution. Information systems which integrate resource management and planning activities, the so-called ERP (Enterprise Resource Planning) systems, are frequently integrated with MES (Manufacturing Execution Systems) systems, which are devoted to the monitoring and control of the production activities at the shop-floor level.

Following this trend, associations of manufacturing companies have started to define process reference models aiming to integrate well-known concepts of business process reengineering, benchmarking, and process measurement into cross-functional frameworks. These reference models are the result of a traditional knowledge engineering approach, where communication, knowledge and enterprise modeling are the main objectives. For example, the recent Supply Chain Operations Reference (SCOR) model defined by the Supply Chain Council [4] has brought a deep impact on business system planning. According to the SCOR model, ERP (Enterprise Resource Planning) products address the requirements of the PLAN, SOURCE and DELIVER processes, while Manufacturing Execution Systems (MES) are the primary component of the MAKE process. Most large and mid-size companies are implementing ERP systems but, as they attempt to extend enterprise systems to the production plant, it becomes evident that a gap in operation functionality exists. This leads manufacturing organizations to look for a new approach to plant operation management. The ability to create an effective link between plant resources and production management, together with tight closed-loop integration among plant, suppliers and customers has become more and more necessary.

Recently, an innovative REPAC (Ready, Execute, Process, Analyze, and Coordinate) model [5], focusing on the MAKE activity of the SCOR model, has been proposed, in order to obtain software environments for the management of the modern manufacturing enterprise. In this new REPAC-model, manufacturing is not a "static" process. It is the result of a continuous flow of actions and information inside the enterprise. Data is as much an enterprise's resource as raw materials, and in this respect, the information is also manufactured according a proper workflow. In particular, REPAC addresses all of the processes required to operate the plant, and coordinates all factory activities with the rest of the logistic flow.

Finally, the editorial by M. Aparicio [6] also introduces some recent examples of agent based architectures applied in the manufacturing domain. However, as assessed in [6], while simple agent technologies for notification and personalisation exists, there is much yet to make Internet connectivity more communicative, adaptative, and goal oriented - in a word, more intelligent.

It is important to observe that the information managed in MIS is subject to different requirements and has different features according whether the communication flows within or outside the enterprise. While inside the enterprise the knowledge networking focuses more on the workflow management and corporate memory, outside the enterprise, different capabilities are requested. One example is the communication need of international manufacturing networks to face rapidly changes in global market opportunities and to develop jointly global competitive capabilities [7]. Another example is the need to develop knowledge-based electronic commerce [8], taking into account technologies such as data mining. In fact, data mining approaches based on a wide range of assessed computational techniques (i.e. artificial neural networks, fuzzy logic, machine learning, statistics, expert systems, and data visualization) have provided new intelligent tools for automated data mining and knowledge discovery, with a deep impact on current practices used in manufacturing and directly affecting the production processes.

In conclusion, knowledge will be more and more added in MIS design, and, due to the distributed nature of modern manufacturing, intelligent agent architectures are likely to be more and more used with this goal.

3. Agent technology for workflow management in manufacturing

A basic idea of an agent-based workflow is shown in fig.1

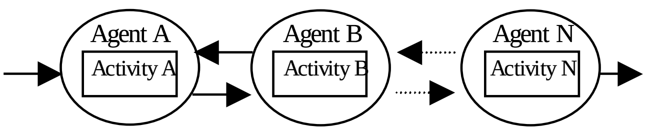

Figure 1. Agent Based workflow

A simple example of workflow architecture is referred to ADEPT project by BT labs [9]. The ADEPT system consisted of multiple software agents, which negotiated concurrently with each other in order to reach agreement on how resources are to be assigned to support a business process. The software agents took full responsibility for business process provisioning, execution and compensation, with each agent managing and controlling a given process task or set of tasks. We can notice the high level of distribution of the system. There are a number of agents and each of them has one simple operation to do. All together they are going to collaborate for a main goal. Agent based workflow systems have been developed by various other research teams each offering their own particular enhancements and feature. Another example of simple architecture for another agent based system, named agent-enhanced workflow, and is showed in fig.2.

Judge et al. [10] recognized the dependency on legacy workflow management systems as well as the cleaner interface they would provide to underlying process tasks. It investigated the integration of agent based process management with existing commercial workflow management systems.

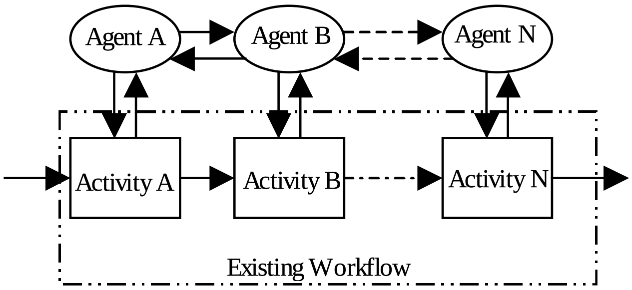

Figure 2: Agent Enhanced Workflow

This approach, in contrast to agent-based workflow combines a layer of software agents with a commercial workflow system.

In a multi-agents system, it must be possible that the agents speak to each other in order to exchange information. For the communication among agents, many languages have been proposed, and probably KQML (Knowledge Query and Manipulation Language) is the most popular [11].

4. The MAKE-IT project

MAKE-IT (Manufacturing Agents in a Knowledge-based Environment driven by Internet Technologies) is a research project, whose objective is the definition and the implementation of "small" software architectures, which we call MAKE-IT agents, for knowledge-based workflow management in manufacturing. In our approach, we aim to define an architecture that can add knowledge to an existing MIS without affecting its normal behavior. In addition, we aim to follow a different approach to the communication inside the manufacturing enterprise and outside it. Finally, we aim to integrate existing and assessed technologies, which are not conceptually distant from the current way of working of traditional MIS.

MAKE-IT agents can perform simple rule-based actions while performing a quite heavy and complex task in their whole co-ordination. The main field of application of the MAKE-IT agents is the workflow management of information in manufacturing enterprises, specifically when their information systems are based on Microsoft Windows architecture and when an effective gateway on Internet is requested.

In the MAKE-IT project, we stress the need of an effective and separate workflow management inside and outside the enterprise. In order to achieve this task, we have oriented the implementation of the current MAKE-IT version taking into account that most MIS of small-medium enterprises (SME) currently uses the Microsoft Windows architecture in our geographic area. The plant data are accessed by RT-DBMS provided by a proprietary SCADA (Supervisory Control and Data Acquisition), for example on the CUBE software, Windows NT Open System, by ORSI Group. The other information can be acquired from / stored in DBMS or by Internet web pages. A simple but great advantage of the MAKE-IT approach is the possibility to coordinate business and plant tasks in the same framework. For example, a text document model could be used to automatically produce quality control documents generated by some process of the shop floor, or some e-mail messages could be generated when malfunctioning conditions of the plant are verifiable by the monitoring of some frequent alarms.

In the MAKE-IT project, we define agents that are non-migratory. In this respect, a MAKE-IT agent is stationary on a computer and can dialogue with other MAKE-IT agents that are resident on the same computer or on other computers connected by a TCP/IP network. The environment where a MAKE-IT agent lives is an information world, where data are stored and retrieved from databases, where documents are to be generated according to events of the production, where information can flow inside the enterprise and from/to the external Internet world. Two main aspects characterize the current version of the MAKE-IT agents: communication and knowledge modelling.

4.1 Communication modeling

In the MAKE-IT approach, we aim to implement intelligent agents that are able to communicate by relational data, using knowledge rules to modify or manage these data, in an environment that is stored in relational databases usually implemented in a Microsoft Windows environment and where information flow should be reliable. XML (eXtensible Mark-up Language) [12] and MSMQ (Microsoft Message Queue) [13] technologies are the technologies that can jointly and effectively realize this objective.

In brief, our approach to agent communication is based on XML tunnelled inside the enterprise boundaries in MSMQ software channels. In other words, a MAKE-IT agent speaks XML since it needs to manage information coming from the relational databases of a MIS. Since XML provides a grammar, a style and a content way to communicate, an agent also needs reliable software channels to exchange messages on. MSMQ is the channel we have adopted in our approach, since MSMQ provides an asynchronous, secure, transactional way to communicate on a TCP/IP connection. MSMQ enables applications running at different times to communicate across heterogeneous networks and systems that may be temporarily offline. MSMQ provides guaranteed message delivery, efficient routing, security, and priority-based messaging.

In addition, while MSMQ focuses on the Microsoft Windows® 95/98 and Microsoft Windows NT® operating system platforms, Microsoft has licensed the MSMQ-MQSeries Bridge (previously known as the FalconMQ Bridge) from Level 8 Systems to inter-operate with IBM's MQSeries. Specifically, the FalconMQ Client provides the MSMQ API on additional client platforms (for example, UNIX, MVS, OS/2, AS/400, Unisys, and VMS), and provides interoperability with non-Windows platforms.

The MAKE-IT communication outside the enterprise boundaries is modelled using traditional Internet applications.

4.2 Knowledge modelling

MAKE-IT agents are able to perform simple tasks that can generally be expressed as a series of if-then conditions. Since we aim to produce a software environment, which can easily configure MAKE-IT agents, in the current prototype MAKE-IT version we have implemented the knowledge of a MAKE-IT agent in a rule based system fired by a proper inferential engine. In this respect, we have modelled MAKE-IT agent knowledge in the CLIPS system shell [14] used by thousands of people around the world.

4.3 The MAKE-IT architecture

The MAKE-IT architecture is based on 3 different levels:

- the MAKE-IT agent generator (MAG)
- the MAKE-IT agent network (MAN)
- the MAKE-IT agent workflow manager (MAWM)

The MAKE-IT agent generator (MAG) allows the knowledge and the communication modelling of the MAKE-IT agents.

The MAG allows the definition and the implementation of a MAKE-IT agent and can also be taken into account as a sort of compiler for MAKE-IT agents.

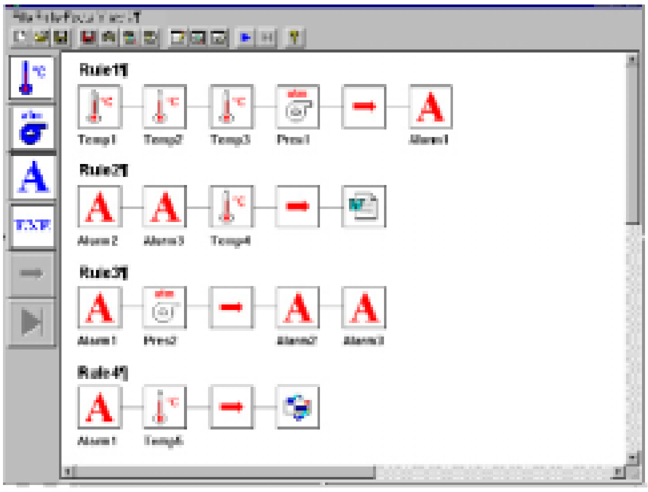

Figure 3. The graphic environment of the MAKE-IT knowledge modelling environment.

MAG allows implementing communication modelling, knowledge modelling, MAKE-IT agent generation.

The MAG communication modelling allows defining the environment where a MAKE-IT agent lives and the channels on which it can communicate. This capability allows defining the MAKE-IT agent identifier and the name of the IP host on which the MAKE-IT agent runs. In addition, it is possible to define the input/output MSMQ queues (host, name of the queue, properties of the queue) on which the MAKE-IT agent can communicate, as well as other Internet communications (Web pages, e-mail etc.) with the external world. Each MAKE-IT agent has also a limited private MSMQ queue that stores as a log file the last tasks performed.

The MAKE-IT knowledge modelling is a graphic environment where variables can be defined and linked together to build CLIPS rules. The MAKE-IT knowledge modelling is two folded.

In the first section, the knowledge engineer is allowed to define the variables, which will be used as graphic objects in the rule based section to embed knowledge in the agent. The values of this data are initialised by a query on specified MIS DBMS whose XML output value is stored in the variable; this value can be updated with a user-defined frequency. A specific interface allows the interaction with RT-DBMS (for example the Cube Real Time DataBase) in order to acquire specific alarms and data process.

In the second rule based section, the objects defined in the previous section can be linked together to form if-then rules. The current MAKE-IT version has a Windows-based interface that allows to define rules and to display them in a graphical environment (fig.3). The term rule means a sequence of Event-Conditions-Actions blocks (that are objects). A rule contains more conditionals and actions objects and it is executed only when an event is triggered as consequence of changes of some state variables. MAG can effectively work as an agent interpreting the defined rules on-line. In the maintenance of the system, MAG allows the continuous improvement of the agent functionality towards an optimisation of the plant system followed by the specific agent.

Finally, MAG allows agent generation, that is to produce a run-time MAKE-IT agent and to run it on the related host. Fig. 3 shows a simple example of knowledge modeling of a MAKE-IT agent working with a RTDB, and managing rules relating shop-floor alarms with current office applications, such as an automatic generation of an e-mail and the production of a text document.

When a MAKE-IT agent "sees the light", it is able to manage XML, to dialogue with other MAKE-IT agents on MSMQ channels, to "work" in Internet if it has relationships with the external world, and to act according to the rule-based knowledge previously modelled in the MAG. In this respect, a MAKE-IT agent cannot acquire experience during its life, but MAG can be used to add further knowledge at any moment.

From a functional point of view, the MAN, where many MAKE-IT agents cooperatively work, represents the knowledge networking of the MIS.

MAWM aims to define the enterprise knowledge-based model of the MIS, that is it aims to manage the coordination and the control of the MAN, representing the MIS knowledge networking. A central manager or coordinator in an agent-based system can be taken into account as an agent with the goal of supervising the activities of a subset of agents. The MAKE-IT agents can generally operate in an autonomous way without the intervention of an overall scheduler for their activities. Such behaviour corresponds to a novel scheduling approach based on the competition and/or cooperation of agents that need some shared resource to operate. In a manufacturing environment, the agent-based approach can be suitable to face the complexity of the scheduling problems by adopting a heuristic that decentralizes the decisions on the basis of the priority of the agents that can be dynamically updated. In this framework the coordination performed by MAWN can be used to force changes in the agent priorities in order to improve an overall criterion.

The current version of the MAWM only provides the possibility to see the current state of the MAN architecture, to switch on/off the different agents working in the MAN in a web based control panel. The switch on/off command is realised by sending a highest priority message to a specific MAKE-IT agent. The broadcast set/reset of the MAN is also allowed.

5. Conclusions

Manufacturing is likely to evolve to a wide number of interconnected Internet/Intranet knowledge based networks.

The MAKE-IT architecture joins the main characteristics and advantages of agent architectures distributing the complexity of the management of manufacturing workflow information according to the enterprise complexity. In our opinion, MAKE-IT agents can represent an open, effective, cheap software architecture, which should satisfy the information needs of modern manufacturing, and that can be simply "add-on" an existing MIS.

From a communication point of view, the MAKE-IT agent architecture internally joins the benefit of the asynchronous, reliable, transactional if requested, MSMQ channel with the XML open standard for structured communication in an Internet oriented information system. With the external world, it uses all the benefits deriving from an Internet communication.

From a knowledge modelling point of view, the MAKE-IT agent architecture benefit of the CLIPS reliable inference engine and of the object oriented user interface.

The current research direction of the MAKE-IT project is two-folded. The first research task is the definition an environment that is able to generate and configure MAKE-IT agents in a more user-friendly way. The second research task is the definition and the implementation of a more complex MAWM that can co-ordinate the activities of the MAKE-IT agents distributed in a manufacturing enterprise information system. Specifically, our current approach is to model the MAKE-IT agent network as a Petri net in which agents concur in the access to information resources and manage them in a workflow of information

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