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Agent-based intelligent system development for decision support in chemical process industry

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ABSTRACT

This paper presents an agent-based intelligent system to support coordinate manufacturing execution and decision-making in chemical process industry. A multi-agent system (MAS) framework is developed to provide a flexible infrastructure for the integration of chemical process information and process models. The system comprise of a process knowledge base and a group of functional agents. Agents in the system can communicate and cooperate with each other to exchange and share information, and to achieve timely decisions in dealing with various scenarios in process operations and manufacturing management. Process simulation, artificial intelligent technique, rule-based decision supports are integrated in this system for process analysis, process monitoring, process performance prediction and operation suggestion. The implementation of this agent-based system was illustrated with two case studies, including one application in process monitoring and process performance prediction for a chemical process and one application in de-bottlenecking of a site utility system.

1. Introduction

In chemical process industry, data and information are important resources apart from materials and energy. The effective management for the variety of information resources becomes necessary for better access and sharing of information, which are vital to collaborative product development and integrated manufacturing (McGuire et al., 1993). However, most of technical and operational information resources of chemical engineering systems are kept in the electronic format, in the distributed network environment. On the other aspect, many software products are used to solve engineering design and operation problems, most of these programs provide their users with significant value when used in isolation, but the interoperation between programs is difficult because of the heterogeneity of these programs, as they might be written at different times and in different programming languages.

Due to the increasing volume and distributed nature of the information resources in the chemical industry, and the complexity of the software solution, it requires a software system with flexible infrastructure to support the knowledge sharing and exchange, as well as software interoperation. Agent technique has been proposed as a way to help people better cope with the increasing volume and the complexity of information and computing resources (Bradshaw, Dutfield, Benoit, & Woolley, 1997). By contrast to traditional software programs, software agents are programs that help people solve problems by collaborating with other software agents and other resources in the network (Bradshaw et al., 1997; Peng et al., 1998). Multi-agent system can be utilized to integrate diversity and heterogeneity of information sources, cooperates the distinct but complementary tasks, and facilitates the interoperation of software or application programs (Sycara, 1998).

Software agents have been proved to be a useful technique in designing distributed and cooperative systems in many industrial and business sectors, including telecommunication, air traffic control, traffic and transportation management (Wahle & Schreckenberg, 2001), supply chain management (Julka, Srinivasan, & Karimi, 2002), and medical care (Jennings et al., 1996). They have also been used for developing distributed systems that can collaboratively solve domain problems over the Internet (Clark & Lazarou, 1997).

In this paper, we present an agent-based intelligent system in support of interoperation of data and services to facilitate information integration, coordinate manufacturing execution, and to help engineers make decisions on the basis of up-to-date information. This paper is organized as follows. Section 2 introduces the basic concept of agent-based system. Section 3 presents the design of multi-agent system for decision-support in chemical process industry, and the implementation methodology of the multi-agent system will be described in Section 4. The system application is discussed in Section 5 through some example scenarios.

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2. Multi-agent system and agent communication

2.1. Multi-agent systems

There are various definitions for the term "Agent". Here we adopt the definition by Wooldridge and Jennings: "An agent is a computer system that is situated in some environment, and that is capable of autonomous action in this environment in order to meet its design objectives" (Wooldridge & Jennings, 1995). A multi-agent system consists of a number of agents that work together to find answers to problems that are beyond the individual capabilities or knowledge of each entity. These agents interact with one another, typically by exchanging messages through the computer network infrastructure. Cooperation and coordination between agents is the most important feature of multi-agent systems (Peng et al., 1998). Agents communicate for the purpose of cooperation and negotiation, learning to improve performance over time (Wooldridge & Jennings, 1999). The collaborations between the agents in a multi-agent system tend to take one agent's output as another agent's input without directly utilizing the agent's built-in knowledge model (Chao, Smith, Hills, Florida-James, & Norman, 1998; Jennings et al., 1996). Unlike those stand-alone agents, agents in a multi-agent system collaborate with each other to achieve common goals (Schroeder & Bazzan, 2002), these agents share information, knowledge and tasks among themselves.

The major advantages of applying agent-based techniques include the following aspects:

(1) Multi-agent systems offer a modular approach for software engineering (Sycara, 1998). The modular architecture that allows for the distribution of the intelligence is more appropriate to deal with diversity and heterogeneity of information resources. This feature also enables us defining a multi-agent architecture allowing the integration of tools already available, as well as to add others when they become available.
(2) Agents can further incorporate legacy programs by building wrappers around the program that manage interactions with other systems (Genesereth & Ketchpel, 1994) and require only minor modifications as programs are changed or replaced. This will facilitate the interoperation ability of software or application programs.
(3) A multi-agent system also have capabilities to function in networked distributed environment and cope with system changes (Nwana, 1996), it is more easily to manage the detection and response to important time-critical information that could be updated at any of a large number of different information sources (Cutkosky et al., 1993; Soler et al., 2002).
(4) Application of agent-based systems will help to enhance system performance in the aspects of computational efficiency, flexibility and reusability (Moreno, Sánchez, & Isern, 2003). System development, integration and maintenance are easier and less costly. It is easy to add new agents into the multi-agent system, and the modification can be done without much change in the system structure (Peng et al., 1998).

2.2. Agent communication

Cooperation and coordination of agents in a multi-agent system requires agents to be able to understand each other and to communicate effectively with each other. For such communications to be efficient, multi-agent system infrastructure includes the two key components to support agent cooperation (Garcia-Flores & Wang, 2002): a common agent communication language (ACL) and a shared ontology (Wooldridge, 2002). The agent communication language is a specification of a communication language to be employed by the agents for the interaction processes. It enables agents to base their messages on common syntax and semantic. Ontologies allow agents to agree about the meaning of concepts.

A number of ACLs have been proposed, in which Knowledge Query and Manipulation Language (KQML), Knowledge Interchange Format language (KIF) (Finin, Labrou, & Mayfield, 1997) and FIPA's agent communication language (FIPA ACL) (FIPA00023, 2000) are used most frequently.

In addition to the common communication language, agents must also share the same conceptual model of the domain problem in order to understand the concepts and get effective communications. In the terminology of the agent community, agents must share a common ontology (Sansare & Shah, 2001). Ontology is defined as specification schemes for describing concepts and their relationships in a domain, it provides a formal description of entities and their properties, relationships, constraints and behaviour (Garcia-Flores & Wang, 2002). If two agents are to communicate about a specific domain, it is necessary for them to agree on the terminology that they use to describe this domain.

3. Multi-agent system for decision support in chemical process industry

In this section, we present the proposed multi-agent system framework for decision-making support and cooperative manufacturing in chemical industry. Process simulation, rule-base decision support, artificial intelligent technique are integrated in this system for process analysis, data processing, process monitoring and diagnosis, process performance prediction and operation suggestion.

3.1. Multi-agent system design

The multi-agent system structure is shown in Fig. 1. In this system, agents are designed to capture and access information in distributed electronic repositories, to support software interoperation and knowledge integration, sharing and reuse for the purpose of collaborative manufacturing. In the multi-agent system, process related data and information are kept in the system knowledge base in the format of process models, heuristic rules and database. Process models include process simulation models, predictive models, optimization and scheduling models. These models might be developed utilizing different computing languages and software. Heuristic rules provide process operation and events action guidance according to historic or experts' experience. Historic data and real-time operation data of plant operation are kept and processed in this system. Information on expert knowledge and technical resources related to the chemical manufacturing process are also provided in the knowledge base.

The system uses a number of agents with different tasks to access the information resources, to share or reuse the information and models. They collaborate to solve the engineering and management problems. Ontologies are used to specify the infrastructure of the agent-based system, and to characterize the information content in the underlying data repositories and the exchanged messages between agents.

In this system, the information sources can be stored in distributed locations. Legacy components such as databases, process simulation and scheduling models and software are wrapped up as resources within particular agents to provide the interoperation ability between the software components. Therefore, the system infrastructure supports communications between previously established application software and programs for process simulation, process performance prediction, process scheduling and optimiza-