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An agent-based service-oriented integration architecture for chemical process automation ☆

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ABSTRACT

In reality, traditional process control system built upon centralized and hierarchical structures presents a weak response to change and is easy to shut down by single failure. Aiming at these problems, a new agent-based service-oriented integration architecture was proposed for chemical process automation system. Web services were dynamically orchestrated on the internet and agent behaviors were built in them. Data analysis, model, optimization, control, fault diagnosis and so on were capsuled into different web services. Agents were used for service compositions by negotiation. A prototype system of poly(ethylene terephthalate) process automation was used as the case study to demonstrate the validation of the integration.

1. Introduction

Automation system is essential to run chemical processes safely and efficiently in the large scale plant. It can gather information automatically from various sensors, analyze operational situations and take control actions. Extended functions are integrated into automation system, such as exploring more profitable opportunities, optimizing process, scheduling, and planning. Nowadays, automation system is integrated with business and supplier databases [1]. The increasing automation system is dependent on many applications, which are connotation-packaged, stand-alone and distributed.

Due to the distributed nature and the hierarchy architecture of chemical process automation [2], flexible framework is required to support information sharing and exchanging, as well as software interoperation. Some feasible frameworks have been developed to meet this need. Multi-agent systems (MAS) [3] were firstly applied in control systems to make them more adaptable and manage their complexity [4]. Many applications [5] have proved the success of MAS in the context of discrete manufacturing. In terms of MAS in continuous process, some work has alzso been done. Teppo Pirttioja [6] and Antti Pakonen [7] developed agent based process automation systems separately. Gao [8] presented an agent-based intelligent system to support coordinate manufacturing execution and decision-making in chemical process industry. Though agent-based solutions for enterprise integration have been an active area in the past ten years, industrial support is lacking on the development and deployment of practical agent applications. Besides MAS, holonic manufacturing is being developed as a possible solution in the next generation manufacturing systems because of its consistence with the nature of chemical process automation. McFarlane [9] studied the development of automation systems in continuous manufacturing and discussed holonic technologies in steel rod rolling mill. Chokshi [10] applied holonic principles in chemical process industries which supported flexible unit operations to dynamically integrate and collaborate with others when the production conditions changed. Though holonic architecture is appropriate for hierarchy system, the concrete technology support is missing. Compared with holonic manufacturing, agent technology is a suitable approach for the implementation of holonic and reconfigurable manufacturing control applications [11].

Different from MAS and holonic manufacturing, Service Oriented Architecture (SOA) is a new framework which is often implemented using web service technology. SOA provides a communication platform between distributed and heterogeneous systems and applications. Web service-driven industrial systems are defined as next-generation systems [12]. For industrial automation, a service oriented paradigms named SIRENA project [13] has been used as a case study. It is easy to reconstruct the automation system referring SIRENA. However, SIRENA only considered intelligent devices. In fact, more intelligence in process automation should be embedded in automation system. It is obvious that only SOA cannot solve all the problems.

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In order to address the numerous facets of huge process automation, combination among heterogeneous technology was raised. Among these, the combination of SOA and agents received more attention recently. Poggi [14] discussed the agent-based service oriented structure for system integration. Shen [15] integrated collaborative intelligent manufacture based on agent-based service-oriented integration architecture, in which every agent core was built into a web service. Rishi [16] combined service oriented architecture with agent technology which is used for business service mappings. Liu [17] proposed a multi-agent-based service-oriented architecture for inter-enterprise cooperation system and established the basis for transforming the inter-enterprise cooperation business models into multi-agent-based SOA components. Considering good prospects of MAS and SOA, Huhns [18] even presented an agenda for the deployment of such solutions.

Combination of agents and web service technologies into a cohesive solution avoids the weaknesses of each individual technology and reinforces their individual strengths [19]. Though the combination method has been used in many manufacturing systems, no related system is reported in the domain of chemical process automation, as far as our information goes. In reality, traditional control systems built upon centralized and hierarchical control structures present a weak response to change and are easy to shut down by single failure. Aiming at these problems, this paper proposed a new agent-based service-oriented integration architecture for chemical process automation, wherein web services were dynamically orchestrated on the internet using agent behaviors built in them. A prototype system was illustrated as the case study to demonstrate the validation of the method.

The rest of this paper is organized as follows: Section 2 provides an introduction of SOA and web services. Based on these technologies, Section 3 discusses the hierarchy architecture of chemical process automation and provides an analysis of ontology. The integration structure based on agent and SOA is illustrated. In Section 4, a typical chemical process automation system of poly(ethylene terephthalate) is integrated based on the new architecture as a case study. Section 5 concludes the paper with some perspectives.

2. Service-oriented Architecture and Web Service

MAS have been a research topic in computer science already for a long time which can be found easily in many books. So this paper focuses on reviewing service oriented architecture and web service technology.

Service Oriented Architecture (SOA) is a new framework which utilizes services as underlying elements for developing applications. It is used to support the development of rapid, low-cost, interoperable, evolvable and massively distributed applications. Web services are currently the most promising technology to implement SOA. As an interface, web services are proposed mainly to make the information of the original isolated sites communicate and share with each other. A series of open Internet-based standards are used in web service, including Simple Object Access Protocol (SOAP), Web Services Description Language (WSDL) and Business Process Execution Language for Web Services (BPEL4WS). Web service can be used in any environments (Windows, Linux) which support these standards.

There are several key technologies when building and using web service. The first is how to describe data. XML is chosen as a standard description method. In order to transmit data in any environments, SOAP is used as an information exchange protocol. Web service uses WSDL to be understood by users. UDDI is a protocol of Universal Description, Discovery and Integration, which is a platform-independent, XML-based language for describing business on the Internet. With all of these, web services can go well beyond simply exchanging information to accessing, programming, and integrating application services encapsulated within old and new applications.

Services are autonomous platform independent computational elements and they could be described, published, discovered, orchestrated and programmed using XML for the purpose of developing massively distributed interoperable applications. These standards together provide an open XML-based mechanism for application interoperability, service description and service discovery.

3. Chemical Process Automation Based on Agent and SOA

3.1. Analysis of chemical process automation

In chemical process, automation system is concerned with managing and controlling the physical activities, aiming to execute the plan and monitor the process of the product. With the automation system, the process is required to exhibit a number of desirable characteristics such as efficient, flexible, reliable and safe operations, and their seamless integration with supply and distribution chains. Due to the complexity, multiple levels of control are involved, as illustrated in Fig. 1. The higher levels deal with strategic or tactical issues. For the temporal horizon of days and weeks, the planning is concerned. Within a shorter temporal horizon, scheduling is defined to respect a specific criterion. In the lower levels, the real-time operational issues include the process control conventionally. For higher efficiency of process operation, this level is expanded to cover optimization, steady state modeling dynamic modeling and process control. Also, monitoring and diagnosis are essential parts of the whole system. It is obvious that the automation system is suitable to be integrated with hierarchy architecture. In the architecture, the global visibility of control afforded by higher levels in terms of wider time and physical scopes enables the system to behave in a predictable and stable manner when the conditions are planned and stable.

3.2. Integration architecture

It is obvious that the process automation conforms to hierarchy architecture. In another point of view, the nature of the system is distributed. So the automation system can be seen as the combination of parallel services and agents in five levels which is illustrated in Fig. 2. At the bottom of the architecture is the physical process, which provides information for other software application. Above are different automation systems which are put into use in different times and different operational systems. Considering the heterogeneous characteristics, these applications are encapsulated into fine-grained services. For the cooperation of these services, agents with different functionalities are constructed above these services. The objective of agents comes from the results of planning and scheduling which are provided by ERP or other applications. All of these are located in same or different physical positions and custom users interact with the automation system by local or remote clients. Each level is discussed in detail as follows.

3.2.1. Physical process level

In the chemical plant, a process can be seen as a composition of units interconnected through piping streams and transferring equipment. The process units use the utilities supplied by utility suppliers to perform their process tasks as specified in the product recipe. In the physical process, materials are exchanged to execute the processing tasks. Additionally, real-time information is shared on implementing the basic control functions. From the automation point of view, the interactions of information maintain the physical process running at the target settings.

Information of the process comes from controllers and instruments running on different units. For seamless connection and interoperability in industrial automation, OPC is applied to exchange information. In the application, process operational data and functionalities can be made available as services in a vendor independent fashion [20]. Work is under way to standardize information models for physical device information, analyzer devices, plant operation and maintenance, batch control and PLC programming [21]. The operation modules take care of the activities of a process automation service through using the models and updating the run-time data structures.