Re-configurable Industrial Automation

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Abstract - Distributed automation is the highest level of automation and the main trend of distributed automation lies at self-organizing and re-configurable systems by means of distributed intelligence. This paper presents the state of art of self-organizing and re-configurable systems. Then, a new framework is put forward for Re-configurable Industrial Automation, which combines the latest advances of computer science in Service-Oriented Architectures.

Index Terms – self-organizing re-configurable system, distributed intelligence, service-oriented architecture, distributed automation.

I. INTRODUCTION

Automation has evolved over three generations, as depicted in Fig. 1. At component automation level, main concerns are mechanization and algorithmization of mechanical, electrical or biological processes, which may end up with various islands of automation. At systems automation (system of components), concerns are systems integration, integration of automation. At the distributed automation level, main concerns are re-configuration and self-organization of autonomous sub-systems in a distributed environment. Distributed automation is so called the system of systems (SoS).

Coordination & Organization Required

Distributed Automation (System of Systems, SoS, Among Domains of Autonomy)

Systems Automation (System of Components, Among System Components)

Component Automation

Fig. 1. Levels of automation.

In the last decade, self-organizing and re-configurable systems have been investigated and developed in agile and re-configurable manufacturing systems, distributed embedded systems, and autonomic (distributed) computing systems. These are converging towards a major trend. At the same time, research and technological challenges are obvious for generic and effective approaches.

II. STATE OF THE ART IN SELF-ORGANIZING AND RE-CONFIGURABLE SYSTEMS

In recent years, the importance of self-organization and self-management for complex distributed systems has been widely recognized, e.g., in computing and communications [1].

Following IBM’s launch of its autonomic computing initiative in 2001 [2,3], many IT industry world players including HP, Cisco, Microsoft, Oracle and many others, have also launched autonomic computing or related programs or initiatives. In academic communities, autonomic computing has drawn intense interests and various conceptual paradigms of autonomic computing have emerged [4-11]. Also there has been a common trend in autonomic computing and autonomic communications [12], or the so-called autonomic informatics [13]. Clearly, the general framework of autonomic computing can be formulated as a type of self-managing systems [14], the technical foundations of which lie in feedback control, adaptive control, robust control, etc.

The developments of middleware systems of complex distributed computing environments, e.g., internet computing, Grid computing, have brought forth a range of technologies related to dynamic resource management/allocation, including, e.g., distributed job scheduling and re-scheduling techniques, resources brokering/trading protocols, etc. [15-18]. The middleware layers are quite robust and self-adaptable over the heterogeneity and dynamism of the infrastructures and resources in complex distributed computing environments. However, such adaptability and robustness are heavily dependant upon the natures of the infrastructures and resources, and consequently the level of scalability of the middleware systems is mostly very much confined.

Service-Oriented Architectures are able to detach resource dependency problem effectively [19-21]. Through virtualization of heterogeneous resources, Service-Oriented Architectures provide a uniform framework for the encapsulation of resources and the reuse and dynamic composition of massive services in complex distributed computing environments [22,23]. By this way scalability is profoundly enhanced. There are two highly challenging issues existing with Service-Oriented Architectures. Firstly, how massive services interact with one another so as to generate a sensible composition for fulfilling the desired objectives of users and domains. One way is to incorporate domain-specific contexts into the run-time dynamic discovery and composition processes governed by the protocols under which services interact with one another. Secondly, while significant works...
have been undertaken in recent years on service choreography and orchestration, dynamic service composition, etc. [24][25], there is still a lack of an engineered approach to self-organization of Service-Oriented Architectures.

Distributed embedded systems share many of the important characteristics of general distributed systems and in recent years have been explored in middleware based approaches and Service-Oriented Architecture methodologies. However, distributed embedded systems have their own distinctive characteristics. In particular, distributed embedded systems are subject to very high level real-time requirements and hard physical constraints, while normal middleware based approaches and Service-Oriented Architecture methodologies in general distributed systems are not necessarily aimed at real-time applications and constraints satisfaction. More importantly, although modern infrastructures of distributed embedded systems have widely been made network/internet enabled, when compared to those of non-embedded normal ICT infrastructures, distributed embedded systems infrastructures are normally quite limited in their network/internet, software and service-oriented compliance, programmability, re-configurability, manageability and adaptation. Such limitations and constraints of distributed embedded systems make it very hard to directly transfer middleware based approaches and Service-Oriented Architecture methodologies in general distributed systems to distributed embedded systems.

Self-organization has been widely studied since 70’s in a broad range of disciplines, including physics (thermodynamics, entropy), chemistry (catalytic reaction dynamics), biology, ecology, economics, sociology, and organizational theory, etc. [26][27]. In terms of formation mechanisms, self-organization phenomena can distinguish between emergent self-organization, e.g., swarm intelligence, and pro-active (goal-directed) self-organization, e.g., organizational re-structuring in human organizations. Existing works in emergent self-organization are mostly concerned with observations, modeling and simulations of natural and socio-economic phenomena, e.g., the emergent behaviors, positive/negative feedback mechanisms, communications and stimergy, etc. [28-29; 30-31]. Along the line of emergent self-organization, new types of optimization techniques have emerged, e.g., ant colony optimization [32-33], particle swarm optimization [34-36]. Existing works in pro-active self-organization are mainly concerned with holistic self-organization of multi-agent systems [37-39]. While concepts of holonic architecture (i.e., holarchy), holonification operations and strategic adaptation transition rules have been defined, there is still a lack of an engineered approach to the design, construction and implementation of holonic self-organization of multi-agent systems.

Holonic manufacturing systems is an important application of holonic self-organization in distributed embedded systems. [40] presented a reference architecture for holonic manufacturing systems. The reference architecture contains three basic holons, i.e., product, resource and order, and has established UML diagrammatic description of the relationships among the holons. [41] presented a description of holonic enterprise. While holonic manufacturing systems has been seen as a new paradigm of intelligent manufacturing, there are still many issues around holonic manufacturing systems. Particularly, there is a lack of definition of holonification operations necessary for holonic manufacturing systems, there has not been a software architecture to support holonic manufacturing systems, and most importantly, no relationship has been established on how the dynamically generated architectures of holonic manufacturing systems to reach the specifications of manufacturing automation hierarchy.

III. FRAMEWORK OF RE-CONFIGURABLE INDUSTRIAL AUTOMATION

By combining Service-Oriented Architectures and Grid Computing with distributed automation, a new framework can be put forward for re-configurable industrial automation, depicted in Fig. 2. This is a vision for complex distributed process industrial automation.

Two research directions of re-configurable industrial automation are as follows.

1) Service-Oriented Architecture of complex distributed industrial automation systems. This involves how to introduce Service-Oriented Architecture of computer science into complex distributed industrial automation, and how to agentify complex distributed industrial automation by means of service-oriented virtualization, not by mechanical mapping; and

2) Self-organizing re-configurable industrial automation based on the above service-oriented virtualization. This is not about re-configurable industrial process, but re-configurable automaton.

In the contexts of complex distributed industrial automation, e.g., chemical plants, from a system point of view, an industrial enterprise normally consists of many sub-systems, such as CAD (computer aided design), CAPP (computer aided production planning), CAM (computer aided manufacturing), production automation system MES (manufacturing execution system), ERP (enterprise resource planning), CRM (customer relation management), SCM (supply chain management), MIS (management information system), EDI (electronic data interchange), E-business, DSS (decision support system), and so on. They constitute a complex distributed system environment, infrastructures of which are nowadays widely network/internet enabled. Each sub-system performs their functions. More importantly, these sub-systems mostly operate on heterogeneous distributed software platforms of their own, for this situation, architecture of complex distributed systems is very important for agile industrial automation. In fact, systems architecture covers many domains such as basic data integration, information integration, process-wide integration through to enterprise-
wide integration, industrial alliance (e.g., supply chain consortium).

Nowadays, system architecture is confronted by two challenges. One is system-of-systems architecture. In the environment of global economy, system architecture involves many aspects, such as coordination and synchronization of global distributed systems, privacy, security, dependability, scalability, and so on. More dependable technologies are needed to guarantee all these aspects of integrated systems. The other challenge is the distinctive nature of process industry. Different from discrete manufacturing industry, process industry has its own intrinsic properties. For example, operation optimization and production planning in process industry are different from scheduling problem in discrete manufacturing.

To address the challenges above, the following aspects are especially of interest.

1. Generic theoretical framework and methodology based on multi-agent systems self-organization needs to be developed, which is suited to complex distributed industrial process automation, e.g.,
   - How to agentify sub-systems in complex distributed industrial process automation;
   - How to implement component-level services of complex distributed industrial process automation;
   - How to dynamically synthesize workflow services;
   - How to realize real-time self-organization mechanism based on dynamic formation and disbandment of holons;
2. Multi-agent service-oriented software infrastructure is to be developed for complex distributed industrial process automation.
   - How to construct and implement holonic multi-agent software platform for complex distributed industrial process automation;
   - How to develop Service-Oriented Architectures for complex distributed industrial process automation, including MES, process control/automation system, ERP, MIS, DSS, E-business, production planning and scheduling system, operation optimization;
   - How to transform functional cooperation problem into dynamic composition, synchronization and management of services.

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