AGENT TECHNOLOGY AND PROCESS AUTOMATION

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Application of agent technology to design and implementation of process automation systems has been proposed by some researchers. The purpose of this paper is to review current knowledge of this issue. The starting point of the study is the functional requirements of a process automation system. The requirements are compared with the models of agent systems, including multi-agent communication and coordination methods and single agent operational principles. Proposed partially agent-based process automation system architectures are shortly discussed, too. Some comparisons to the technology of the existing process automation systems are also made.

1. INTRODUCTION

Process automation is an application domain that has traditionally been characterised by requirements emphasizing safety, reliability, efficiency and quality. Process automation has not typically been an early adopter of new information technologies like software agents. However, some research has emerged concerning the application of agent technology to the implementation of process automation systems. This effort has been motivated by recent developments in the requirements and technology of process automation systems and on-going research in related fields, particularly automation of discrete manufacturing.

Our aim in this paper is to study how agent technology could be used to fulfil the requirements of process automation systems. The match between the operational principles of process automation systems and agents is discussed along with the possible utility of agent technology for the design objectives of process automation systems. The discussion is based on published results in this research area, including some by the authors, and some analogous developments in automation of discrete part manufacturing.

2. RECENT DEVELOPMENTS IN PROCESS AUTOMATION SYSTEMS

Process automation systems are undergoing developments both with respect to the importance of various requirements and the technology available for their implementation. One requirement that has been reported to have increasing importance is operational flexibility. This means that an automation system should manage more changes in production tasks and equipments without sacrificing other operational requirements [5][20]. Other recently emphasized requirements include system availability and changeability. Abnormal situations need to be observed before they affect production objectives. Necessary changes to automation applications and equipments need to be done more easily, willingly in plug-and-play fashion. All these requirements may be seen as consequences of more market-driven production.

The novel technical developments that could be used to fulfil the new requirements include enhancements in instrumentation, networking and software techniques. Intelligent instruments have computing capabilities that are currently not fully utilized. They can be connected to other instruments via field busses and to remote information systems via local area networks and the Internet. These communication channels might have more usage in the future. Object-oriented programming and component technologies have been adopted in the implementation of information systems oriented parts of automation systems. Usage of XML and web services has recently been studied as possible systems integration methodology. Lastly, there is the currently rather open question how to apply agent technology in process automation systems.

3. PROCESS AUTOMATION FUNCTIONS AND AGENT MODELS

The core functionality of a process automation system is the control of a physical production process. However, there are also other functions in a process automation system with significant roles (see Figure 1). One such functionality is abnormal situation handling. Another functionality is process and equipment data collection and processing for various purposes including control, monitoring, maintenance and process improvement. Actually, it has been argued that the importance of the other functions than control is growing and process automation systems are becoming more like information systems. In addition to the mentioned operation time functions, there are also the design time functions of application development and system integration.

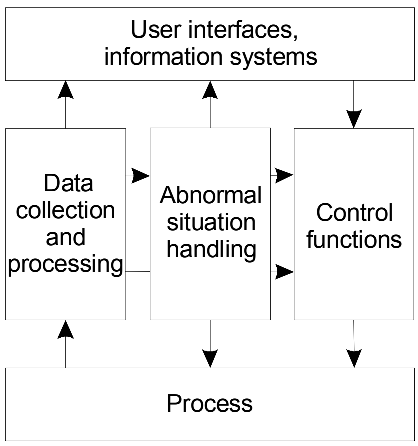

Figure 1. Selection of essential functions in a process automation system.

In the context of process automation systems agent technology has mostly been considered from the control functionality viewpoint. Agents have been proposed as enhanced controllers with features useful for fulfilling the new flexibility, availability and changeability requirements [5][14][17]. The primary means to these objectives is thought to be extended coordination within a distributed control system. Agents have been considered as goal-oriented, semi-autonomous controllers in a distributed control system. They are expected to coordinate control operations both in normal and abnormal situations. How this coordination should be performed in different situations is currently a research topic. Another related research question has been the internal operation of the agents that enable the combination of control operations with coordination. These questions along with agents' role in other functions of a process automation system are discussed in subsequent chapters.

3.1 Control functions

The control functions of a process automation system can be divided into three types with different characteristics: continuous, discrete and batch control [11]. Batch control is a higher-level function with less stringent response time requirements. Discrete and continuous control are lower-level control functions, which require very predictable and often real-time operation [2]. The properties of the control functions affect particularly the conventional quality and efficiency objectives posed on a process automation system. However, they have an essential influence on the flexibility objective as well. The control functions have operating regimes in which they operate effectively. The scopes of these regimes restrict the flexibility of a process automation system.

In control functions the overall role of agents has usually been proposed to be decision-making concerning actions in one controller and coordination of these decisions with other controllers. Depending on the type of control this general form of operation appears in different forms. In continuous control agents have been proposed for selecting appropriate control algorithms for different process states [21]. In a general form this approach would create a network of so-called intelligent controllers, where each continuous controller is supervised by a knowledge-based one. The coordination mechanisms needed for such distributed intelligent controllers have not been studied much though. For continuous control of shared resources an auction-based coordination algorithm has been studied [24], but this can be regarded as an initial study of a special case.

In discrete control agents have been proposed for running control sequences [19]. Each agent could contain a planner that creates runnable control sequences from plan templates during run-time. The planners are proposed to be coordinated with a Contract Net type of coordination mechanism. The approach has been demonstrated with simple examples. However, it is not yet clear if this approach is feasible in more general situations. Depending on the type of interdependencies between planning processes in different agents a more powerful coordination mechanism than Contract Net might be required. Another open question is if planners can fulfil the predictability and response time requirements of discrete control.

In batch control the planning task is somewhat similar to production planning in discrete manufacturing. Thus it is natural that similar coordination methods, e.g. Contract Net [13], have been proposed for both of these problems. Again, the criticism of the Contract Net as a coordination method for production planning might apply to both of these cases. It has been argued to produce non-optimal production plans [15]. This would suggest that more advanced coordination methods are needed in agent-based batch control, too.

3.2 Abnormal situation handling

While the control functions are usually designed for normal operating conditions, abnormal situations are handled with specific functions. First abnormal situations need to be detected and diagnosed. After that the process is typically run into a safe state followed by manual restoration. The effectiveness of abnormal situation detection and diagnosis affect mainly the safety and reliability objectives. On the other hand, automatic restoration and fault-tolerance could increase system flexibility, by allowing undisturbed production also in exceptional situations.

The role of agent technology in abnormal situation handling has more been studied from the restoration and fault-tolerance viewpoint than from fault detection and diagnosis perspective. The process of agent-based restoration has been regarded quite similar to discrete control. The agent-based controllers are proposed to create restoration plans and coordinate them via Contract Net type of negotiation protocol [4][18]. The criticism of agent-based discrete control can be argued to apply also to agent-based restoration. Even though the approach seems to work in simple examples its feasibility in more complicated situations is not known. Furthermore, if the restoration involves changes in continuous control the situation becomes even more complicated.

The application of agent technology for fault detection and diagnosis has not been studied very extensively in the domain of process automation. One proposed role for agents in diagnosis is the integration of several knowledge-based diagnosis systems [7]. Another possibly interesting concept in the context of agent-based fault detection and diagnosis is distributed data mining [5]. The question if distributed data mining or other methods could be used to develop agent-based versions of fault detection and diagnosis algorithms for process automation systems has not been addressed in reported research.

3.3 Data collection

A large amount of data about process and equipment status is collected from instrumentation and communicated to various receivers both inside and outside of a process automation system. The receivers of this data include e.g. operator user interfaces, controllers, abnormal situation handling procedures and MES, ERP and maintenance systems. Data is combined from several sources and processed for refined status information. A large part of this processing is currently performed outside the automated control system. However, intelligent instrumentation creates a possibility to move a larger part of this functionality into the automation system. Filtering of data at instrumentation level could make its processing easier at other levels and improve system changeability.

The usage of agent technology for data collection functions in process automation has not been studied by researchers so far. However, some research results from other application domains might be interesting also from the viewpoint of process automation applications. The concept of information agents [3] contains the idea that different data sources are wrapped within agents. Information agents are proposed to cooperate and make inferences in order to support more flexible queries.

3.4 System integration

The previously mentioned control, abnormal situation handling and data collection functions create a need to integrate separately designed systems both inside a process automation system and between it and external information systems. The integration need to information systems is largely caused by the data collection from the process automation system. Another source for integration need is engineering systems used for automation application development. The internal integration requirement is caused mainly by the control and abnormal situation handling functions. Further integration effort is needed for different user interfaces, which nowadays can be remote and mobile. Finally, recently proposed mobile sensors might create a different kind of integration need in the future [1]. These devices are less static parts of an automation system than conventional instrumentation. The difficulty of these integration tasks has a primary effect on system changeability.

The essential possible advantage of agent technology in integration of process automation systems is the agent-based communication model, particularly the FIPA-standard [8]. It might be argued that FIPA-based communication could encapsulate the modules of a distributed system, like a process automation system, more efficiently than exiting methods, e.g. OPC, or other recent developments, e.g. web services. This could facilitate the objective of plug-and-play type of integration in process automation systems. However, it can also be argued that FIPA-based communication cannot fulfil all communication needs in a process automation system. It is questionable if FIPA-based communication, in its current form, is suitable for real-time communication as indicated by research in telecommunication domain [12]. It seems reasonable to start from the higher-level functions if using FIPA-based communication as an integration mechanism in a process automation system.

3.5 Application development

Development of process automation applications is characterised by merge of two separate traditions of system development. Continuous and discrete control functions and abnormal situation handling procedures are usually specified by specialised automation languages, e.g. function blocks [9][10], while data collection and systems integration are increasingly implemented with methods adopted from information system development, e.g. object-oriented programming and component technology. The application development methods have a primary effect on system changeability. The weakness of traditional automation languages has been reported to be their limited support for modularisation and reuse.

The meaning of agent technology for application development in process automation has not been studied much yet. It is likely that agent communication and coordination are quite reasonable to be specified in terms of FIPA. Specification of agents' internal operation is a more complicated issue. The application development with proposed agent architectures, e.g. reactive and BDI-models, seem to be fundamentally different than with current methods of process automation. A simple approach would be to use different methods for specification of separate parts of the system. However, also a reasonable merger of agent-based and process automation application development methods could be useful.

4. PARTIALLY AGENT-BASED PROCESS AUTOMATION SYSTEM ARCHITECTURE

Some system architectures for the implementation of agent-based functions in a process automation system have been proposed [13][16][17][19][22][23]. Many of these have been based on a wrapper model. An agent layer is build on top of a traditional process automation system as illustrated in Figure 2. Its purpose is to monitor the process and equipment status, run higher-level control tasks and reconfigure the control logic when needed, e.g. in batch changes and abnormal situations. It could also perform part of data processing functions and interfacing to external systems. Its communication structures are designed to be more flexible than the statically wired structures in current process automation systems.

Some proposals have been made for the internal architecture of a process automation agent as well [17][19]. Probably the most often presented one of them is based on the model of planning agents (see Figure 2). According to this model an application is defined as plan templates, which are used by the planner during run-time for dynamic plan construction. The planning process can initiate coordination between agents while action synchronisation is done during plan execution. This model seems to be quite suitable for modelling of discrete control operations including system restoration sequences. However, it is difficult to say if applications designed in this way can fulfil the predictability, response time, safety and reliability requirements of process automation systems. Furthermore, also some very different architectures for partially agent-based control systems have been proposed [25]. Thus the question of suitable agent-based architecture for process automation systems is still open.

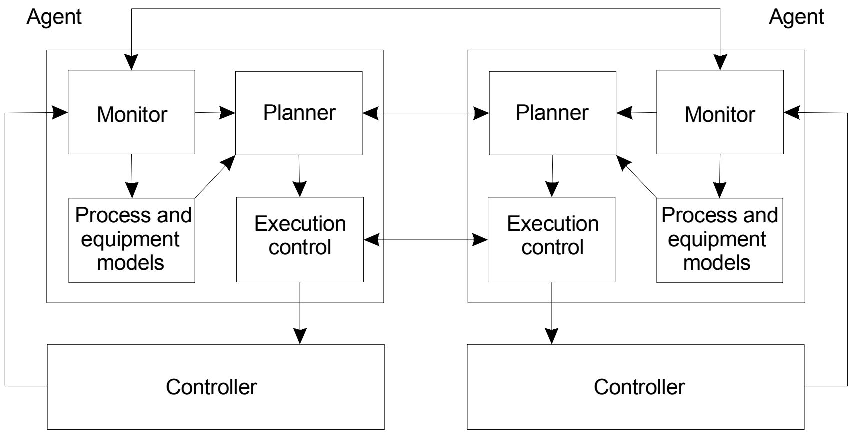

Figure 2. One of the proposed partially agent-based process automation system architectures.

There is a somewhat common understanding among the researchers about reasonable agent application structure for a process automation system. A hierarchical application structure that reflects the structure of the controlled process has usually been regarded useful [17]. The hierarchy can consist of e.g. three layers: the process, sub-processes and equipments. The task of the higher-levels in this model is to set goals for lower levels and monitor their performance. Coordination could be performed either among peers or via supervising levels. However, with some process automation equipment, e.g. mobile sensors [1], there might also exist dynamic structures, which can be difficult to model with the presented static hierarchical model.

5. CONCLUSIONS

Agent technology has attracted some interest among the researchers of process automation systems. Agent technology has been primarily seen as a possible method for gaining better flexibility, availability and changeability properties in process automation systems. Agent-based communication methods have been regarded as a suitable encapsulation method for distributed process automation systems. The possibility to utilize agent-based coordination methods for more flexible distributed control has been preliminary studied as well. Probably the most adequate target for agent technology in the process automation hierarchy has been identified at the higher, non real-time levels. Even though partially agent-based process automation systems might seem promising, the knowledge of them should currently be considered as preliminary. There are very few reports about applications that are evaluated with simulated or real test processes.

There are some very essential open questions concerning the application of agent technology to the design and implementation of process automation systems. First, the coordination methods proposed for agent-based control require further development and evaluation before they can be regarded as reliable. The same judgement holds for planning techniques proposed for agents' internal operation. Basic doubts include non-deterministic results and unacceptable response times. Secondly, it might be useful to have a broader view to the functionality of a process automation system than just control. How to arrange agent-based fault detection and diagnosis or data collection and processing might be worthwhile topics for research, too. Thirdly, if proper agent applications can be developed it would be useful to assess to which extent they actually help to gain the desired objectives of flexibility, availability and changeability. At the same time it should be studied to if agent applications are able to retain the more conventional requirements of safety, reliability, quality and efficiency.

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