Multi-Agent System Enhanced Supervision of Process Automation

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Abstract

This paper studies issues concerning the application of user configurable cooperative information agents for monitoring tasks in process automation. Within this application area the amount of information gathered from the processes has been growing vastly and the supervising personnel has been minimized in the production plants. As this trend seems to keep going further, the end users need more effective information handling tools. However, the information overflow problem has also shown up in other application domains, and it is useful to discuss the similarities and differences with solutions used in these areas. This paper proposes an agent-based architecture to support active monitoring of the changes in process related data situated in various heterogeneous information sources. This approach is based on a BDI agent model, where individual user-configurable information processing modules are flexibly linked. The approach is demonstrated with an industrially inspired test scenario.

1. Introduction

Process automation has become an application area where many ordinary ICT (information and communications technology) based solutions are used. This is a combined result of relatively mature ICT solutions being available and the needs of the domain. However, building automation applications based on off-the-self software tools, e.g. from office automation, has lead to a situation which does not support end user decision making in an optimal way. For example, hard-coded web based reporting solutions are laborious to maintain when the system setup evolves in time.

There is a demand for system architectures and engineering tools that could be used as a basis for building effective supervising tools. Often useful process information is generated and gathered effectively but stored in separate systems so that it becomes frustrating to search and combine later on. There is a need for various types of monitoring services that are easy to set up, use and maintain in increasingly complex process setups.

This paper is motivated by the fact that there is a growing number of ICT based solutions used in process automation but these solutions are not directly applicable to process automation problems. Also, there is a strong need to effectively combine these separately developed systems. As information agent-based solutions have been successfully applied to similar integration problems in dynamical and heterogeneous setups, it is proposed as a solution also in this paper.

The paper is outlined as follows. Chapter 2 will discuss aspects of user configurability, the present situation in the process automation domain, and state-of-the-art information handling technologies. The developed multi-agent based architecture for process automation information tasks is presented in Chapter 3. An industrially inspired experiment implementing the developed architecture is presented in Chapter 4. Finally, the conclusions and further research directions are pointed out in Chapter 5.

2. Users, emerging information technologies, and process automation

2.1. User needs within process automation

Users within process automation have different needs compared to ordinary users of information systems, where usually changes in information are the result of user activities. In process automation the system is primarily running on its own, without the need of active user intervention. However, supervision is needed at all times to observe critical changes in operation. These changes may be caused by various reasons, such as variances in input materials, device malfunctions, or changes in the process management. Furthermore, as the processes are becoming more complex and the total efficiency requirements are high, there is a need for more flexible and powerful tools to supervise them [27].

There are numerous user profiles in process automation supervision tasks. Operators supervising the immediate day-to-day process operations in the control room are definitely one of the most important ones. There has been rather thorough research in this area, and tools for operators are quite mature, but there is a need to develop them further [10]. In addition, there are users such as servicemen and system developers who are responsible for operations in physical devices. There is also the viewpoint of the ecomical aspects of the process, which are under the supervision of manager-level personnel. The main interest of managers is the performance of the whole system, but there are times when technical details need to be addressed to be able to draw valid conclusions.

Common to all users in process automation is the need to be able to effectively supervise the changes in the process. These changes may be visible in numerous information systems related to plant operation. Although monitoring tasks have much in common, supervising tools have to be easily personalized to different user needs to be useful. Furthermore, as changes happen without prior notice, the supervising tools should be active and highly automated requiring as little as possible user intervention, following the concept of indirect management [10].

2.2. Solutions from information technology

Nowadays information technology solutions are often based on services. Service related development, such as Web Services (WS, [26]) and Service Oriented Architecture (SOA, [22]), are developing solutions that make many kinds of application-to-application communication possible seamlessly. Even the rather conservative area of process automation is willing to apply WS tools to gain better interoperability [14] and the possibilities of semantic web services within factory automation have been pointed out [11]. Lately researchers have noticed the importance of an explicit definition of the communication [1], leading to the development of implementation languages for representing the semantics. The most important of these languages is the Web Ontology Language (OWL) standardized by W3C [15].

However, the need to further study how individual services are selected and how they can collaborate to provide higher levels of functionality have been acknowledged [5][18][26]. Multi-agent research has already studied the coordination between service providers for some time [5][8][12], and have even developed some standardization for interaction protocols and communication languages (FIPA, [4]). Furthermore, the use of multi-agent systems for process automation has been rationalized by researchers [2], and agent-based diagnostic systems were first applied in industrial settings more than ten years ago ([3][6]). Agents have also been proposed as information mediators in manufacturing enterprise integration [21].

As computers are becoming more powerful it might be useful to have them handle data processing as much as possible. Letting machines do the routine work would release humans to do more advanced work [13]. Furthermore, the idea of *proactive computing* is to put machines in control of the basic actions and let humans watch over and verify that everything is going as planned [23]. When deciding a suitable technology to implement proactive computing, information agents would suit the task perfectly, as they have been designed to proactively acquire, mediate and maintain relevant information on behalf of the user [9].

2.3. Process automation specialties

Process automation is developing towards heterogeneous but interconnected systems communicating with more or less open standards. The amount of measured, stored and available data is increasing rapidly. This is a result of cheaper processors and memory, which are used at all levels of automation. Even at the plant floor level, intelligent field devices with useful selfdiagnostic abilities are available on the market. Increasingly, subprocess control and diagnostics are sold by the vendor as a part of the hardware construction [24]. Furthermore, many sorts of knowledge gathering, maintenance planning, and process optimization software are integrated, one way or the other, to process automation systems. The strongest effort has been related to process operation time information, but recent research has also included the use of design time information [27].

Traditionally, the engineering tools developed within process automation have been mostly related to the immediate control of physical devices. These tools are nowadays rather mature, but there is a need for tools for more effective managing of change situations [20][24]. Furthermore, control engineering tools do not provide enough support for effective information access in dynamic process environments [27].

3. Multi-agent system based architecture for supervised process automation

The multi-agent system architecture presented here aims to provide a basis for building configurable supervising services for users in process automation. These agent-based services rely on flexibly coordinated and efficient access to all process-related information. In this architecture, partly based on previous research in control aspects of process automation [19][20], a society of agents operating in various roles is located in the middle of information sources. The requirements of user configurability are also discussed and the internal design of an agent is represented.

3.1. Use of supervision and its configuration

Although there already are many industrial-strength monitoring and diagnostics solutions available, there are no guidelines or common agreements how these should be configured by the user. Furthermore, there is also a lack of methods for combining these partial solutions effectively. Supervision of process automation differs from ordinary office automation and information systems, so their solutions can not be utilized directly.

Effective supervision of process operation needs a variety of monitoring, searching, and combination capabilities for diverse information objects. In monitoring, the user is interested in changes in data. The simplest monitoring case is watching over one process quantity, e.g. the fluid level in a tank, and this is available in process control environments. However, the monitoring of combinations of multiple values, processed values, or nested changes of values (patterns) is not usually available. Users would also benefit from advanced tools that help with searching through stored data. Furthermore, in complex supervisory tasks some reasoning capabilities would be useful.

An important question is how the user would like to run and configure these supervising functions. On the one hand, there is a question of how to set up and configure this supervising infrastructure. The multi-agent architecture presented in the following chapters is one answer to this question. On the other hand, there is a need to define a formalism or language by which the user can operate and use this infrastructure. This is a more difficult problem, as this language should be as generic as possible, such as, for example, SQL is in data storage related applications. Good quality proposals for this kind of monitoring language are not available, but an example is presented in Chapter 4.

3.2. Agents as information mediators

The objective of the architecture is to operate as a mediator for information from all levels of modern process automation, from physical instrumentation to enterprise-level systems. Figure 1 shows the agent platform located in the middle of various information sources, where it can access information, process it and send it to its clients. The agent platform is taken outside the ordinary process control system to separate information handling from real-time process control. In addition, the agent platform is able to connect directly to all information sources, such as process related knowledge or upper level business systems. The agent platform also has the ability to provide information services to other systems, such that it does not only operate as an information sink.

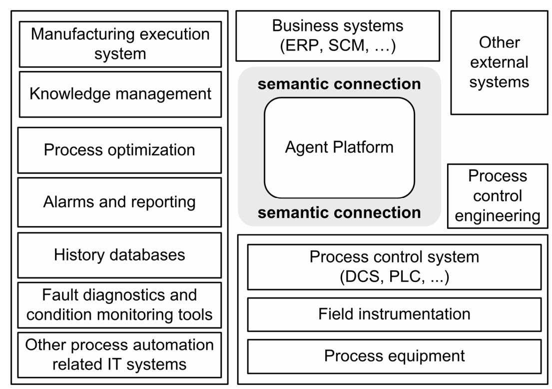

Figure 1. General architecture

To be able to access information from various sources, the agent platform has to have mechanisms to handle the formats and meanings of the information these sources are providing. Therefore, semantic connections are used between the agent platform and other information sources. Technologies for semantic connectivity are available, as mentioned in section 2.2. With a semantic connection it is possible to format information for internal usage and relay it to external computational systems. However, references or ready-made ontologies for process automation domain are largely missing.

3.3. Agents in various roles

The agent society consists of a set of information mediator agents having various responsibilities, or roles, as illustrated in Figure 2. The presented roles are imitations of different types of human operators supervising process automation. The setup of different agent roles also eases the design; there is a natural place for each responsibility or information processing service in the agent society. Currently, there are five different roles: Client Agent, Information Agent, Process Agent, Wrapper Agent and Directory Facilitator. Although roles are predefined, an agent may operate in various roles simultaneously.

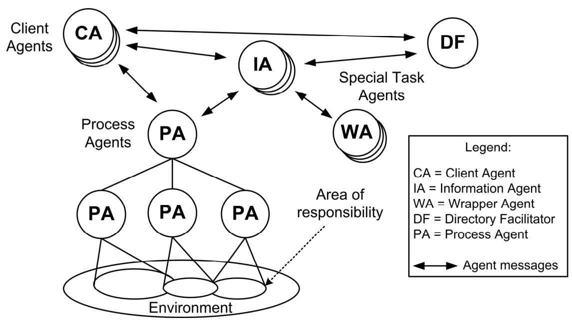

Figure 2. Various roles of agents

Direct use of these supervising services is provided by the *Client Agent* that offers an interface for the human user. These interfaces are usually customized separately for every supervising task. Another possibility for the user to benefit from these supervisory services is to use interfaces and functionalities of external information systems that internally use services that these agents provide.

The key agent type for information processing is the *Information Agent*, which acts as a link between information sources and clients. It provides various information processing services for other agents, including monitoring of changes in data, information searching, and data formatting. Internally an Information Agent decomposes information requests to combinations of smaller pieces of information, pieces that are already known or available via communication with others.

The connection to physical process level is provided by a *Process Agent,* which is responsible for a specified process area and its operations. A Process Agent actively monitors variables and changes for a spatially or functionally divided process area. These Process Agents form a hierarchy based on the physical setup of the process. This hierarchy is a background for the data abstraction; agents at the lowest process level handle detailed measurement information, while agents on the higher levels deal with shorter, more abstract summaries about the process conditions. Furthermore, *Wrapper Agents* are used to access legacy data sources, translate their data to a common format, as well as possibly providing basic data mining services. Finally, the *Directory Facilitator* (DF, standardized by FIPA [4]) is used to manage a list of available agents and their services.

3.4. Configuration of individual agents

The internal operation of the agents is based on a goal-orientated principle, which has its foundation in the BDI-model (Belief-Desire-Intention, [17]). The functionality of an agent is controlled by a configurable manager module that uses a changing combination of individual information processing modules to build up needed functionality. Figure 3 illustrates the general structure of supervising agents. Available information processing modules and their usage vary depending on the role and the setup of the agent.

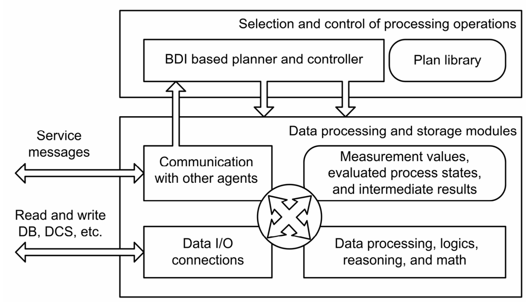

Figure 3. Internal structure of an agent

The motivation to use a goal-oriented operating principle is that it uses concepts that are intuitive for human users and it is suitable for building context-dependent functionalities needed in process automation. For example, operational state of the process may be seen as context when selecting data processing algorithms in monitoring. The use of goals for information processing within process automation is discussed more in [16].

As the information for processing is available in mixed syntaxes and varying semantic, there is a need to convert it to a common ontology. This ontology describes the concepts of the process and its control automation, the concepts used in other IT systems, and the services provided by the agents. Currently, there is a suitable standard language (OWL, [15]) available that also enables simultaneous use of multiple ontologies. Furthermore, a properly defined domain ontology eases the end user configuration work.

4. Example of user configurability

The feasibility of the presented user-configurable supervising architecture is tested with a supervision scenario set by process operators working in the paper industry. Implementation is based on an open source agent system with self-made modules for user configuration and user interface. The design is based on the presented agent architecture, and therefore enables further development of functionalities.

4.1. Implemented agent architecture

The implementation of this agent architecture is based on the JadeX agent framework [7], which offers a good starting point for developing goal-oriented and BDI-model based agents. This framework provides guidelines for agent development and useful tools for software testing. Furthermore, as this framework is Java based and open source it has been possible to enhance its functionalities to suit process automation domain related needs. Ability to extend the current implementation is crucial in the future as more functionality will be added to the system.

4.2. Temporal monitoring scenario

Slowly drifting measurements are one of the hardest problems within process automation. This is because feedback control loops are typically compensating the measurement errors and supervision personnel get tired to watch over multiple values continuously. The most effective way of finding out these kinds of malfunctions is to compare multiple process values together, verifying that combinations of a set of values are in their normal operational range. This kind of monitoring would be especially useful *temporally* when there is much happening in the process otherwise, for example during process startup.

The scenario presented here is an example of user configurable monitoring functionality that automates the supervision of combinations of multiple values. The way users configure monitoring functionality is based on an approach adapted from the field of *Constraint Satisfaction Problems* (CSP) [25]. In this approach the user sets up the monitoring tasks with a set of constraints, where combinations of measured process values are compared to constant values. The actual monitoring is then performed by an information agent with the cooperation of process agents.

The feasibility of this temporal monitoring has been put to test in the process of pulp bleaching, a part of paper making. Within bleaching there is a need to verify the correct operation of sulphur dosage control, which is dependent on sensitive pH measurements. Correct operation of this control loop cannot be verified directly, but instead there is a rule of thumb that the dosage of sulphur dioxide (SO_2) should always be less than the dosage of sodium hydroxide (NaOH). Figure 4 illustrates how the functionalities and operations are divided between agents when the rule is seen as a constraint ($NaOH - SO_2 > 0$).

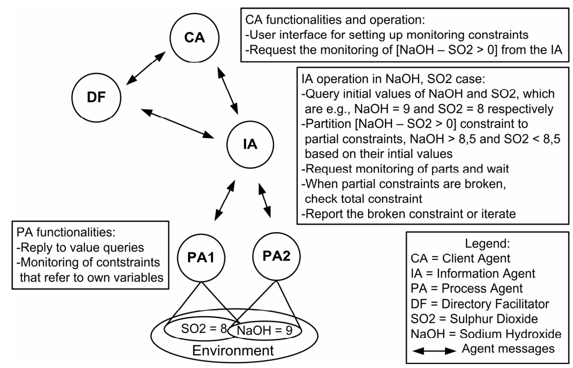

Figure 4. Monitoring example with constraints

With a set of constraints the user is capable of defining a variety of monitoring tasks that are related to the operation of the process. The module responsible of partitioning the given constraints does not restrict the number of constraints or used variables. Furthermore, as an information agent finds relevant peers dynamically, based on their registered process responsibilities, the overall configuration does not need to change when user-defined constraints change. However, defining monitoring tasks with mathematical constraints is not necessarily user friendly. How a user would like to define monitoring tasks and what the user interface should look like are obvious subjects for further research.

5. Conclusion

In this paper, the possibilities of a multi-agent based approach for creating user configurable supervision of process automation are discussed. This research is motivated by the capabilities that information handling agents provide when compared to user requirements within process automation. First, a set of possible supervising functionalities is represented along with a discussion about user configurability. Then, a generic agent-based architecture capable of searching and processing information in a dynamic process automation environment is presented. Finally, the implementation of the architecture is shown in a test scenario.

In the future, the presented approach will be used as a starting point to build up more complex supervisory tools. These tools should provide the user with an easy and flexible configurability with traceable and reliable operation. Along with the user configurability issues the future research should cover a more detailed design of basic operating principles of agents' information processing. Furthermore, the architecture should be tested more extensively in industrial settings.

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