Computers and Chemical Engineering 60 (2014) 182–196

Contents lists available at ScienceDirect

Computers and Chemical Engineering

journal homepage: www.elsevier.com/locate/compchemeng

Implementation of multi agents based system for process supervision in large-scale chemical plants

Sathish Natarajan, Rajagopalan Srinivasan*,[1]

Department of Chemical and Biomolecular Engineering, National University of Singapore, 10 Kent Ridge Crescent, Singapore 119260, Singapore

ARTICLE INFO

Article history:
Received 15 February 2013
Received in revised form 20 August 2013
Accepted 22 August 2013
Available online 9 September 2013

Keywords:
Process retrofits
Transitions
OntoSafe
Monitoring
Fault diagnosis

ABSTRACT

Modern chemical plants have evolved into extremely large and complex operations. Operators rely on the plant automation system, particularly the DCS, for managing the plant operations which themselves have become open, and involve multiple third-party technologies, instruments, and software. The structural-, scale- and dynamic-complexity makes it challenging for operators to infer the conditions in the plant quickly and make timely decisions, especially during abnormal situations. A process supervision system that assists the operators by providing holistic decision support is therefore essential. Here, we propose an multi agents based architecture for supervision of large-scale chemical plants. The key insight in the proposed architecture is that the process descriptors used for developing the supervision models themselves are not static and change routinely. The proposed architecture uses an ontology to represent all the process descriptors formally, so that any changes can be captured and their effects propagated seamlessly. This architecture has been implemented as a multi agent system called ENCORE. The detailed implementation of ENCORE is presented and its benefits are illustrated through an offshore oil and gas production case study.

1. Introduction

Modern chemical plants have evolved into extremely large, integrated and complex systems. Two prime examples are Reliance Jamnagar refinery complex in India and Shell's Eastern Petrochemical complex in Singapore. The Reliance Jamnagar facility is fully integrated with a petrochemical refining complex, an aromatics complex, a power generation complex and port & terminal complex. The refinery complex alone has more than 50 process units, which together process the basic feedstock, crude oil, to produce a wide range of products using distillation, cracking, coking, reforming and other unit operations (Anonymous, 2011a). Shell Eastern Petrochemical complex is Shell's largest refining and petrochemical hub, located on adjacent islands, Bukom and Jurong, off Singapore and linked by undersea pipelines. This complex houses the world's largest ethylene cracker and mono-ethylene glycol plant. Operators in such plants find it increasingly difficult to keep abreast of all the information available, infer the condition of the plant and take timely decision to manage abnormal situations. In order to ensure safety and efficiency of operations, a process supervision system that provides operators with decision support during abnormal situations is essential. However, there are several challenges in deploying supervision systems for large-scale chemical plants as described next.

In the past, chemical plants were designed to operate using a limited set of feedstock producing a few products. Nowadays, they are designed to handle a wide range of feedstock and produce a large variety of products. The frequent short-term switching between these results in significant transients during operation. Moreover, the physical structure of the plant itself is amenable to change. For example, certain sections of the plant may be taken offline (for weeks or months) for routine maintenance (leading to short-term retrofits). In addition, long-term changes such as incorporation of new unit operations or processing sections to improve efficiency also occur. Such long-term retrofits in the lifecycle of the plant are particularly common in extremely large complexes such as Reliance's Jamnagar facility (Anonymous, 2006, 2009b). Traditionally, process supervision systems were developed for specific process structure and modes of operation. However, modern day plants change routinely throughout their lifecycle and are structurally and dynamically complex. Hence, process supervision must be *flexible* and capable of adapting seamlessly to short- and long-term plant changes and retrofits.

Operators currently rely on the plant automation system to manage operations. In the past, these systems, like Honeywell's TDC 3000 were proprietary (Samad, McLaughlin, & Lu, 2007) and used custom interfaces to exchange data with field devices. This

* Corresponding author. Tel.: +65 651 68041; fax: +65 677 91936.
E-mail addresses: chergs@nus.edu.sg, raj@iitgn.ac.in (R. Srinivasan).
[1] Current address: Indian Institute of Technology, Gandhinagar, India.

0098-1354/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.compchemeng.2013.08.012

meant that a single vendor by-and-large provided the software and all the hardware for the automation system. Recently, automation systems have evolved from such proprietary architectures to open architectures (Samad, 2010; Samad et al., 2007). Fieldbuses – device level digital communication networks, such as Foundation Fieldbus, Modbus and Profibus allow devices and instruments from different vendors to be used together. Standards like OLE for Process Control (OPC) allow interoperability between automation/control applications, field devices/systems, and windows PC based applications. These advances have led to a proliferation in third party interfaces, systems, and applications. For instance, the automation system in the Jamnagar refinery complex includes a Foxboro distributed control system, Triconex critical control safety system, SimSci-Esscor performance monitoring application, Avantis asset management application, and other off-site automation solutions (Anonymous, 2011b). In order to identify the condition of the plant, a suitable process supervision system must be able to access and use information from such diverse sources. It must *cooperate* and coexist with multiple third party software systems.

Given the extremely large size of modern chemical plants, their automation systems too are large, involving hundreds of thousands of devices and instruments. In Reliance's Jamnagar facility, there are over 20,000 foundation fieldbuses with the capability to control and manage 300,000 process points (Anonymous, 2011b). Hence, the complexity in modern chemical plants have increased both in scale and structure. A single monolithic process supervision method, as is traditionally practiced (Venkatasubramanian, Rengaswamy, Yin, & Kavuri, 2003), cannot be used at this scale. Multiple process supervision methods, each responsible for monitoring different sections or equipment or states are necessary (Ghosh, Natarajan, & Srinivasan, 2011). For instance, one method may supervise the reaction section, another the separation section and so on. These methods will then need to exchange their respective diagnostic results, which should be combined suitably to cohesively identify the overall condition of the plant (Ghosh, Ng, & Srinivasan, 2011) and any abnormality therein. Hence, a suitable process supervision system must allow *collaborative* decision making.

Another recent development is the proliferation of smart self-diagnostic instruments and wireless sensors. As an example, Emerson's Rosemount 3144P temperature transmitter is capable of self-diagnosis and can identify thermocouple degradation and sensor drift (Emerson Process Management, 2010). In addition, these devices can also be used to diagnose problems such as plugged lines, entrained air, cavitation and so on (Emerson Process Management, 2010). With the advent of wireless sensors, process streams that were previously not accessible with wires can now be measured. These sensors can also be moved around in the plant to measure streams on as-needed basis and hence provide transient measurements. Companies such as Chevron and BP have started using these sensors, particularly in their new oil & gas field developments (Carlsen, Skavhaug, Petersen, & Doyle, 2008; Laframboise & Karschnia, 2010; Martin, 2009). A suitable process supervision system must be *extensible* in the sense that it should be capable of using information from self-diagnostic instruments, wireless sensors, novel diagnostic methods and any other form of intelligence.

Some chemical plants are also operated in a remote manner, particularly new unmanned offshore natural gas installations (Anonymous, 2009a). They are often space constrained and lack large-scale computational facilities. However, during abnormal situations the computational load increases significantly as advanced algorithms have to be used for fault diagnosis and the base load, when the process is operating normally, is often significantly different from peak loads. One solution to efficiently manage this is by using remote and *scalable computing*, as used in other industries such as jet engine health supervision (Jackson et al., 2005).

In summary, a suitable process supervision system must have the following characteristics for successful real-world deployment:

1. *Flexible:* Be cognizant of and adjust to plant transients (short-term) and retrofits (long-term) seamlessly.
2. *Cooperative*: Coexist and cooperate with modern automation systems, third party interfaces, and software systems. It should be capable of accessing information from the distributed control system or plant asset management system and provide diagnostic results to these softwares in a suitable form.
3. *Collaborative*: Use collaborative decision making with multiple process supervision methods. These methods should be deployed for different sections, equipment or instrument. They need to exchange diagnostic results that can be suitably combined into a cohesive judgment of the plant condition.
4. *Extensible*: Capable of seamlessly using information from transient sources such as wireless sensors, smart instruments (capable of self-diagnosis), new process supervision methods, human expertise and other forms of intelligence.
5. *Scalable computing*: Capable of distributing the computational load as necessary and remote deployment.

While there is an abundance of literature on process supervision methods (Venkatasubramanian et al., 2003), little attention has been paid to address the challenges described above in deploying these to real large-scale chemical plants with high scale-, structure- and dynamic-complexity. We seek to address this paucity in this work. We demonstrate that an open architecture based on multi agents can address these requirements. Hence, a multi agent based prototype process supervision system, called ENCORE, has been developed and is presented in this paper. The rest of the paper is organized as follows. A literature survey of multi agent systems is provided in Section 2. Section 3 describes the architecture necessary for supervision of large-scale chemical plants. This architecture was implemented as a multi agent system, called ENCORE, as described in Section 4. Section 5 illustrates its application to an offshore oil and gas case study.

2. Multi agent systems

A multi agent system (MAS) is composed of multiple interacting intelligent agents within an environment. MAS are used to solve problems that are difficult or impossible for an individual agent or monolithic system (Sycara, 1998). In multi agent systems, (1) each agent has incomplete information or capabilities for solving a problem; (2) there is no global control; (3) data are decentralized; and (4) computation is asynchronous (Sycara, 1998). MASs have the following key characteristics that are relevant to this paper:

1. *Flexible*: Agents with different abilities can adaptively organize to solve problems that change temporally.
2. *Cooperative*: Agents (FIPA-compliant (FIPA, 2013)) can coexist and cooperate, even with those developed in different software packages.
3. *Collaborative*: Agents can collaborate with each other by sharing information in order to solve problems that are beyond the scope of any one agent.
4. *Extensible*: Agents with new capabilities can be added as they become available or necessary to solve a problem.
5. *Distributed computing platform*: The agent platform can be split on several hosts each executing one or more agents. A host typically corresponds to a Java Virtual Machine (JVM) which is a basic container of agents.