Engineering Applications of Artificial Intelligence 26 (2013) 515–523

Contents lists available at SciVerse ScienceDirect

Engineering Applications of Artificial Intelligence

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

Application of a dual foundation approach for construction of an intelligent system

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ARTICLE INFO

Article history:
Received 23 September 2011
Received in revised form
4 May 2012
Accepted 15 May 2012
Available online 3 August 2012

Keywords:
Semantic web
Ontology
Intelligent framework
CO_2 capture process system

ABSTRACT

This paper presents the development of a decision support system for monitoring and diagnosis of the amine-based post-combustion carbon dioxide (CO_2) capture process system at the International Test Centre for CO_2 Capture (ITC) at the University of Regina. The amine-based CO_2 absorption capture process system consists of dozens of components and generates more than a hundred different types of data. The vast amount of raw data produced by the system are measurements of the many reaction components, valves and pumps. The system operators often find it difficult to quickly detect, diagnose and correct any abnormal conditions that may arise during operation. Therefore, developing a decision support system for monitoring and diagnosis of the CO_2 capture process system which aids the operator in monitoring and diagnosis of the system is a desirable objective. This paper describes development of the system based on the dual foundation of a domain ontology and an intelligent system framework in the domain of carbon dioxide capture process. The developed ontology provides the semantic knowledge foundation; it was implemented in the Knowledge Modeling System (KMS), and the knowledge was stored in the XML format. The intelligent system framework consists of system functions which can use the XML schema provided by the ontology and support the development process. A decision support expert system for process monitoring is a sample system developed on the dual foundation.

1. Introduction

Research on post-combustion CO_2 capture has been ongoing over the past two decades, and the amine-based CO_2 capture process has become one of the dominant post-combustion CO_2 capture technologies because of its efficiency and low cost; this process has been implemented at the International Test Centre for CO_2 capture (ITC) at the University of Regina in Saskatchewan, Canada. Operation of the ITC system involves manipulation of 16 primary components and a multitude of valves and pumps, which generate a huge set of data on the process parameters. Currently the CO_2 capture process system is supervised by the DeltaV (a trademark of Emerson Corp., USA) process control system, which is based on the Object Linking and Embedding for Process Control (OPC) industrial protocol.[1] The DeltaV system is able to provide automated industrial process control and can support automated monitoring and control functions. However, it neither supports data filtering and analysis nor diagnosis of the process systems. As a result, the process engineers and researchers at ITC often need to manually retrieve and analyze the monitored data collected by DeltaV. Therefore, developing a decision support system (DSS) for operation support of the CO_2 capture process system would enhance the efficiency of analysis and monitoring processes. A DSS would (1) provide reliable support to the operators in performing monitoring and diagnosis of the facilities during daily system operations, and (2) help researchers who need easy access to the process data.

In order to provide infrastructure for building this and other such DSS's, a web-based intelligent system framework was built which can support development of different intelligent system modules for diverse functions. In addition, the experts' knowledge and problem-solving methods adopted during operation of the CO_2 capture process system were captured and represented in an ontology model of the CO_2 capture process. The ontology model can serve as the knowledge foundation, which provides semantic guidance in diagnosis and operational decision-making of the CO_2 capture process system.

This paper presents development of the IT infrastructure developed for the CO_2 capture process system which consists of both the intelligent system framework and the ontology model. This paper is organized as follows. Section 2 introduces the CO_2 capture process and background literature about ontology, semantic knowledge and operational support system. Section 3 describes knowledge modeling and ontology construction. Section 4 presents the design of the architectural framework for developing intelligent systems. Section 5 illustrates how the architectural

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[1] The detailed information about OPC protocol can be found at http://www.opcfoundation.org/.

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http://dx.doi.org/10.1016/j.engappai.2012.05.022

framework and the ontology model can serve as dual foundation for building intelligent systems. Section 6 provides some discussions and conclusions, and discusses possible directions for future work.

2. Background

2.1. Application problem domain

The operation of the amine-based chemical absorption CO_2 capture process is described as follows. Prior to CO_2 removal, the flue gas is pre-treated in the inlet gas scrubber, where the flue gas is cooled down, and particulates and other impurities such as sulfur oxide (SO_x) and nitrogen oxide (NO_x) are removed as much as possible. The pre-treated flue gas is passed into the absorption column by an inlet-gas feed blower, which provides the necessary pressure for the flue gas to overcome the pressure drop in the absorber. In the absorber, the flue gas and lean amine solution contact each other counter-currently. With the high temperature steam provided by the boiler, the amine selectively absorbs CO_2 from the flue gas. The amine solution carrying CO_2, which is called CO_2-rich amine, is pumped to the lean/rich heat exchanger, where the rich amine is heated to about 105 °C by means of the lean amine solution. The heated CO_2-rich amine then enters the upper portion of the stripper. In the stripper, CO_2 is extracted from the amine solution, which is recovered as the lean amine solution. Most of the lean amine solution returns to the lean amine storage tank and is then recycled for CO_2 absorption. A small portion of it is fed to a reclaimer, where the degradation by-products and heat stable salts (HSS) are removed. The non-regenerable sludge is left behind in the reclaimer and can be collected and disposed of. The CO_2 product and water vapor from the top of the stripper is passed through a reflux condenser. Most water is condensed there, and the residual amine solvent passes back to the stripper column reflux section to help desorb CO_2 again. The CO_2 product enters a CO_2 wash scrubber, where the CO_2 gas is cooled down to a desired temperature of 4 °C. From there, the CO_2 can be vented into the atmosphere or passed through a dryer and purification unit to produce food grade quality CO_2 (Zhou et al., 2009). In order to maintain the normal operation of this process system, hundreds of parameter values generated by this process need to be monitored and analyzed, and an automated intelligent system can support the task.

2.2. Background literature

2.2.1. Intelligent system frameworks

An operation support system usually consists of an on-line operation manual, and components for fault diagnosis, equipment maintenance management and a multimedia interface (Rao et al., 2000). Chiang et al. (2001) reveal three general solution approaches for supporting the tasks of monitoring, control, and diagnosis including data-driven, analytical, and knowledge based approaches. Each approach has its own strengths and weaknesses. Integrating multiple solution approaches could eliminate the constraint of each approach. However, the task of integrating multiple solution approaches can introduce more complexity to the system (Uraikul et al., 2007). In the literature, many relevant research projects on building automated systems for supporting process operations can be found; these include the research work on intelligent monitoring systems and intelligent system architecture for process operation support (Rao et al., 2000). A good summary is presented in Uraikul et al. (2007), which suggests that there are four important architectural frameworks for developing an intelligent system for monitoring and control. Firstly, the framework of integrated real-time workstation (IRTW) developed at the Laboratory of Intelligent Systems in Process Engineering (LISPE) (Han and Stephanopoulos, 1995), which provides a generic integrated framework for combining different functionalities. The weakness is that the rigidly structured organization of the framework can cause problems if the environment is not stable. The second framework is the DKit hybrid framework (Mylaraswamy and Venkatasubramanian, 1997), which has been adopted for design and implementation of the abnormal events guidance and information system (AEGIS). The blackboard architecture of DKit provides a global data structure that allows the problem-solving state to be available while each module can be kept isolated (Albayrak and Krallmann, 1995). The third framework is the on-line operational support system (OOSS) for fault diagnosis (Chan and Wang, 1999), which consists of an integrated knowledge discovery and data mining system able to guide the development of different intelligent systems. The fourth system is the platform for developing an INTElligent Multimedia system for On-line Real-time applications (INTEMOR) (Rao et al., 2000), which was an extension based on a framework called the Integrated Distributed Intelligent System (IDIS) proposed by Rao (1991). It includes modules for data acquisition, data calibration, condition monitoring, fault diagnosis, maintenance, on-line help, operation manual, historical data management and knowledge-base creation. INTEMOR has the advantage of having a relatively flexible architecture, which can integrate various types and levels of knowledge representations such as rules sets, past solutions and process models.

2.2.2. Ontological modeling

There is abundant literature related to ontological modeling; here, the objective is to briefly explain some background concepts about ontological modeling. An ontology is an explicit specification of a conceptualization, and ontological engineering involves the study of the organization and classification of knowledge. With the growth of the semantic web in the past decade, ontological engineering has been greatly emphasized. An ontology enables automated processes or agents to more effectively share information. The conceptual structures defined in a domain ontology provide the basis for machine-processable data on the semantic web. An ontology can be used as the basis of knowledge acquisition tools, which are used for collecting domain knowledge or generating expert systems (Chan, 2003). An ontology can serve as a metadata schema, which provides a defined vocabulary of concepts with explicit machine-processable semantics. By defining shared and common domain theories, ontologies support semantic as well as syntactic exchanges, thereby helping people and machines to communicate concisely. Hence, the semantic web's success significantly relies on the construction of domain-specific ontologies (Maedche and Saab, 2001). Fundamental to the semantic infrastructure are ontologies, knowledge bases, and agents along with inference, proof, and sophisticated semantic querying capabilities (Uschold, 2003). The machine-processable semantics can then be utilized by various intelligent systems for advanced process control and management.

3. Knowledge modeling and ontology construction

3.1. Ontology design

The CO_2 domain ontology was constructed based on the knowledge obtained during the knowledge acquisition process, which consists of the three phases of knowledge elicitation, knowledge analysis and knowledge representation. The primary knowledge source was the experienced operators of the CO_2 capture process system at ITC. The Inferential Modeling Technique (IMT) provided the knowledge engineer with a template of knowledge types to help identify specific knowledge elements