A Survey on Standards and Ontologies for Process Automation

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Abstract. Agent technology and model-based engineering have proven potential in various prototypical implementations and academic environments but are not yet well accepted in industrial practice. However, it is evident that upcoming manufacturing systems need to integrate more rigorous foundations of semantics than currently applied data models and architectures but the conformance with industrial standards is crucial for their acceptance.

This paper presents a survey on standards and ontologies for the process domain carried out during the first phase of the project BatMAS, which aims at the integration of a system ontology for providing an extensive knowledge base. On the one hand, the knowledge base should be accessed by an agent-based system for batch process automation and on the other hand, it should provide access for various functionalities of a complete automation solution.

Keywords: Ontology · Standard · Batch process · Survey

1 Introduction

Domains such as the food and beverage industry are considered to be very dynamic due to changing market demands, product innovations, new types of packaging as well as new production technologies and equipment. Consequently, flexibility is a key requirement for production plants in such domain, even though the oftentimes historical development of production infrastructure results in a heterogeneous and complex automation landscape. Moreover, the applied industrial software used for process control, human machine interface, supervisory control and data acquisition (SCADA) systems, building automation, management information systems, etc., tends to be very diverse. Typically, the needed functionalities are implemented in various types of software solutions, ranging from pure "island"-solutions, focused on a certain service with limited extensibility, to packages offering interconnectivity, modularity and a development

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platform. Even though the same data sources from the production floor are commonly taken as basis, these different systems incorporate numerous information flows and functionalities, e.g. for data pre-processing, archiving, filtering, processing and presentation. Hence, any changes of the production infrastructure will require the update of the various functionalities in all these different systems, resulting in extensive engineering time and costs.

As a consequence, automation solutions need to evolve in response to the rapidly changing demands to new production processes but also to their growing complexity. Intelligent process control systems are required, which offer a direction towards solving the interoperability problems within the manufacturing life cycle as well as between software applications. In this context, introducing concepts such as artificial intelligence is regarded as promising for the process industry [1]. The aim of applying semantic and agent technologies is thus to increase the flexibility in industrial control [2]. Most reported agent-based approaches focus on discrete processes but agent technology is also well usable in the process domain according to the analysis presented in [3].

The general ideas of agent technology for increasing the flexibility of production systems already range back several decades [4]. Together with other approaches like ontologies for model-based engineering, they are part of the evolution into endeavors nowadays denoted as cyber-physical systems [5] or Industry 4.0 [6]. However, despite the potential benefits of applying such approaches, the industrial environment has not yet broadly adopted these actually old but finally feasible ideas. Concerning the application of model-based engineering, an obstacle is seen in the required data and information. Instead of having these available in standardized data formats involving an according formalization, they are mostly organized in classical office documents such as Word, PDF or Excel, which impedes automatic analysis processes or model creation [7].

Accordingly, upcoming manufacturing systems need to integrate more rigorous foundations of semantics than currently applied data models and architectures [8]. Besides, as standards represent a consensus on the semantics of terms and definitions in a domain, being compliant with them results in an increased reusability and applicability in industrial practice [9]. Generally, the issue of standardization is considered to be a major challenge concerning the industrial acceptance of semantic and agent technologies [10].

This paper gives an overview on standards and ontologies for the process domain. The literature research represents the first phase of the recently started project BatMAS (Batch Process Automation with an Ontology-driven Multi-Agent System) for not reinventing the wheel during the process of creating a knowledge base for the project's envisaged agent-based system and the typically attached functionalities of a complete automation solution.

This paper is structured as follows. Section 2 briefly introduces the project BatMAS and its requirement for a system ontology. An overview of relevant standards and their according Extensible Markup Language (XML) realizations is given in Section 3. Section 4 presents reported ontologies with a focus on the process domain. Finally, the paper is concluded in Section 5 with a summary.

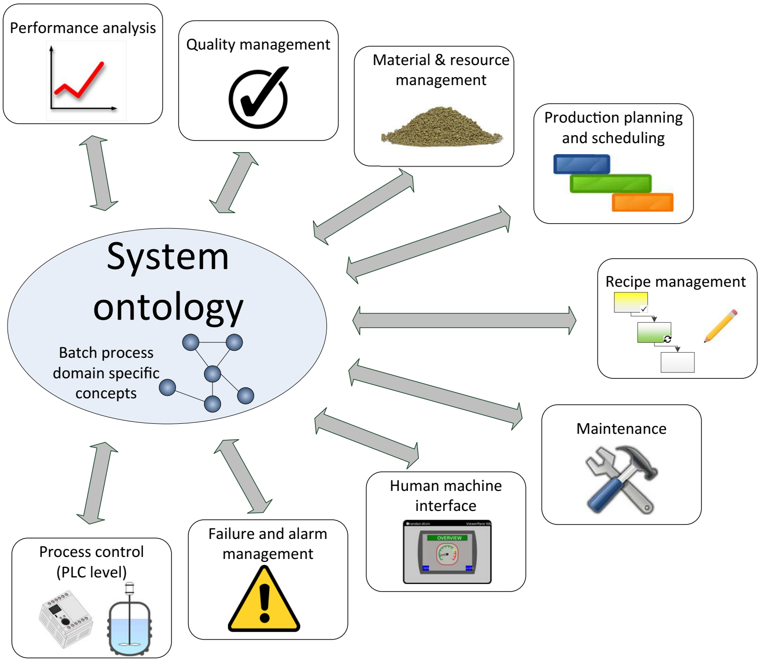

Fig. 1. BatMAS system architecture with a system model and an agent approach for batch process automation.

2 The Project BatMAS

The project BatMAS shall cover two aspects: a system ontology offering extensive data for various functionalities in conjunction with an agent-based approach for batch process automation. Moreover, for reducing the application engineering efforts of the agent system, control code generation mechanisms are investigated.

Fig. 1 presents the typical functionalities of a process control system on various control levels. They were provided by industrial project partner Copa-Data, which possesses broad experience regarding industrial control systems in various domains including batch process automation. Commonly, the shown functionalities rely on data sources located on the production floor and thus data stored in Programmable Logic Controllers (PLCs). However, for achieving flexible SCADA software that integrates these functionalities, it is of interest to develop an extensive and adaptable system model as a core data source with more flexibility than the typically rigid PLC data structures.

In general, the system ontology shall incorporate a representation of the batch process domain concepts. The aim is to achieve an extensive semantic data model for vertical and horizontal data integration and interoperability between the various physical and virtual components. Moreover, it shall represent a universal and consistent data structure to be accessed by typical functionalities and services such as performance analysis or recipe management besides from providing data also in an understandable format for human operators. The project BatMAS is based on previously carried out research on agent technology for the batch process domain [11,12] but shall enhance the concepts concerning compliance towards industrial standards as well as applicability and integration in engineering processes and commercial tools.

3 Standards for Process Automation

A range of industrial standards exists, which represent a consensus on the semantics of terms and definitions covering various levels and scopes of industrial automation. In the following, relevant standards for process automation and their realizations in XML are presented.

The standard IEC 61512 [13], based on ANSI/ISA-88 Batch Control, introduces a framework for the specification of requirements for the batch process domain and for their translation into application software. IEC 61512 provides reference models and structures as well as definitions concerning processes (process model), physical equipment (physical model) and control software (procedural control model) as well as recipes in the domain of process automation.

BatchML [14] is an XML implementation of ANSI/ISA-88. It consists of a set of XML schemas using the XML Schema language (XSD) that implement the models and terminology of the standard. It provides a set of type and element definitions such as master recipes, control recipes, recipe building blocks, equipment elements, batch list, and enumeration sets.

Based on ANSI/ISA-95, the multi-part standard IEC 62264 [15] describes an information exchange framework for the integration of enterprise-control systems aiming to achieve the implementation of enterprise systems and control systems that interoperate and easily integrate. Part 1 focuses on the characterization of hierarchical models and terminology in the operational management and control domain claiming to improve the communication between mentioned entities. On this basis, the scope of Part 2 is the definition of object models and attributes of the exchanged information including personnel, equipment, physical assets, materials, and process segment information. A generic specification of the mentioned models assures the applicability in a wide field of domains.

As an implementation of ANSI/ISA-95, MESA introduced Business To Manufacturing Markup Language (B2MML) [16]. It consists of a set of XML schemas using XML Schema language (XSD) that implement the data models described in the ISA-95 standard.

The standard ISO 15926 [17] titled "Industrial automation systems and integration – Integration of life-cycle data for process plants including oil and gas production facilities" describes a generic data model and reference data library for process plants. Its seven parts cover the classification of data and information, plant or facility reference data, a format for information exchange as well as query and transfer protocols. The reference data library (RDL) is a publicly maintained class collection comprising technical equipment items such as pipes, instruments, buildings, or activities used in process facilities.

With XMpLant [18], an ISO 15926 complying framework was introduced, that includes an XML schema implementing the classes defined in the reference data library. Comprising interfaces to and from the major process plant applications it enables the integration of information across these applications. This integration is accomplished by the use of a mapping subsystem which defines the relationships between external and ISO 15926 inherent models.

The standard IEC 62424 [19] defines a graphical representation of process plants in pipe and instrumentation (P&I) diagrams focusing on the functional requirements instead of the technical realization, as well as a format for data exchange between process engineering P&I tools and process control engineering tools. The described format CAEX (Computer Aided Engineering Exchange) is a neutral, object oriented, XML-based data format for storing hierarchical plant information.

AutomationML (Automation Markup Language) [20], also denoted as IEC 62714, is a dataformat based on CAEX for the storage and exchange of plant engineering information. Referenced in the IEC 62424 standard, the aim of AutomationML is to interconnect engineering tools in various disciplines, including electrical design, process engineering, process control engineering, PLC programming, robot programming, etc. The specification includes the characterization of topology, logic, behavior, geometry and kinematic models.

Table 1 shows the aptitude of the analyzed standards for the typical functionalities and services of an automation solution. Of course none of the standards is designed for covering all aspects but by taking several standards into account, a solution could be designed for maximizing vertical and horizontal data integration and interoperability.

Table 1. Aptitude of the analyzed standards in regard to typical automation solution functionalities.

	Batch process domain specific concepts	Performance analysis	Quality monitoring	Material resource management	Production planning scheduling	Recipe management	Maintenance	Failure and alarm management	Human machine interface	Process control (PLC-Level)
IEC 61512 BatchML	X					X				X
IEC 62264 B2MML		X	X	X	X		X	X		
ISO 15926 XMpLant	X						X		X	
IEC 62424 CAEX	X								X	
IEC 62714 AutomationML	X						X		X	X

4 Ontologies for Process Automation

The previous section elaborated on a range of standards for process automation. However, inconsistencies can and do exist within the definitions and relations within various standards, which is exacerbated by extensions defined by individual manufacturers. In this context, Deshayes et al. propose a general architecture for designing ontologies for standards integration and conformance [8]. The architecture is composed of four levels with different sets of ontologies. While the vendor ontologies are defined by individual companies, the standards ontologies represent a more generic definition of the terms or concepts. According to their name, the domain ontologies are used for describing a specific domain and can be used for checking the consistency between standards ontologies. Finally, core ontologies incorporate generic concepts crossing multiple domains with the aim for maximized shareability and reusability.

Regarding the fact, that most agent-based approaches rather focus on discrete processes [3], also the majority of reported ontologies have been developed for the corresponding domain of manufacturing systems. A small selection of such ontologies is given in the following before presenting more details on ontologies for the process domain.

The ADACOR ontology integrates concepts for manufacturing components with physical resources (machines, tools, etc.) as well as for production orders, operations and disturbances [21]. The MASON ontology focuses on likewise aspects representing thus an upper ontology for the manufacturing domain [22]. An equipment module ontology with the focus on the functions and behaviors of equipment entities and their connections is presented in [23]. A further ontology for manufacturing processes comprising also the concept of controllers is reported in [24].

Regarding the process domain, Batres et al. provide a set of ontologies for describing plants, processes and products [25]. The concepts are arranged in a formalism as structural, behavioral, and operational interrelated objects for achieving simulation models of physicochemical behaviors.

Furthermore, Batres et al. report of work on an upper ontology for the standard ISO 15926 [26]. As such, the ontology defines top-level concepts for supporting the development of domain ontologies.

OntoCAPE is a formal ontology specified for computer-aided process engineering (CAPE) [27]. Its creators consider it to be a so-called "heavyweight ontology" and thus an ontology that involves axiomatic definitions and restrictions concerning the domain semantics. The ontology has been developed according to six design principles, which are coherence, conciseness, intelligibility, adaptability, minimal ontological commitment, and efficiency. OntoCAPE is separated into several abstraction layers ranging from the Meta Layer on top for describing fundamental modeling concepts down to the Application-Specific Layer providing classes and relations for individual applications in the domain of chemical process engineering. The ontology consists of more than 60 modules that are freely available for download. OntoCAPE has been used already in several projects as for instance concerning chemical plants in the development of a knowledge-based software prototype for the integration and management of scattered engineering design data [28].

Further work extends OntoCAPE in regard to modeling operational processes. The Work Process Modeling Language (WPML) [29] allows the representation of behavioral and funcional aspects of a process making use of OntoCAPE concepts in conjunction with additional concepts defined for operational processes. Moreover, the authors demonstrate the possibility of integrating the structural concepts of ANSI/ISA-88 in WPML.

Process supervision represents another aspect not covered by OntoCAPE itself. However, an ontology denoted as OntoSafe [30] provides the means for representing states and conditions and thus including faults of plant components but also of process sections. With this ontology it is possible to specify the dependencies between process descriptors such as flowsheets with a supervision system. OntoSafe utilizes a set of partial models of OntoCAPE extended by another partial model for describing the afore mentioned concepts. OntoSafe has been evaluated in conjunction with an agent-based system in several simulations in the frame of a case-study concerning the domain of oil and gas production.

The Purdue Ontology for Pharmaceutical Engineering (POPE) is an ontology specifically made for the pharmaceutical process domain [31,32]. Its aim is to provide guidelines and support decision making during the product and process development. As a consequence, concepts for defining materials, formulations as well as operations are pivotal for this ontology and its usage. Besides, also mathematical models and their usage are covered by POPE in the framework of OntoMODEL, which is a tool for mechanistic mathematical model management [33].

Based on concepts taken from OntoCAPE as well as POPE, the ontology OntoReg introduces a regulatory domain for automating the regulatory compliance in pharmaceutical production due to the tight legislation in this domain [34]. By applying this approach, the regulatory requirements can be translated into tasks to be carried out using a reasoner and an according rule engine.

Muñoz et al. present an ontology for batch process automation denoted as BaPrOn [35]. The ontology is mainly based on the standard ANSI/ISA-88 integrating its structural models for processes and physical equipment. Moreover, a focus in the ontology is laid on representing recipes according to the standard. It is designated for handling diversity in scheduling problem representation as well as for allowing an effective data sharing and information flow [9]. Combined with a scheduling algorithm, the ontology has been utilized in several use-cases for showing its reusability. Further work is concerned with integrating also other hierarchical levels according to the standard ANSI/ISA-95.

In a previous project denoted as PrOnto, the authors of this paper developed an ontology for representing the physical components of a process plant [12]. On the basis of this ontology, a path finding algorithm is employed for dynamically calculating routes from one component of the system to other ones taking criteria such as failure states of components into account.

Table 2 shows the aptitude of the reported ontologies for the typical functionalities and services of an automation solution. It can be seen that none of the presented ontologies provide concepts for all of these functionalities. However, nearly all of them are covered by one or more ontologies with the exception of human machine interfaces for process automation.

Table 2. Aptitude of the reported ontologies in regard to typical automation solution functionalities.

	Batch process domain specific concepts	Performance analysis	Quality monitoring	Material resource management	Production planning scheduling	Recipe management	Maintenance	Failure and alarm management	Human machine interface	Process control (PLC-Level)
MASON		X		X			X			X
ADACOR				X	X	X		X		X
Lohse et al. 2006					X					X
Alsafi & Vyatkin 2010					X					X
Batres et al. 2002	X			X						
Upper Ontology ISO 15926	X				X		X	X		X
OntoCAPE	X	X		X	X					X
WPML	X				X	X				X
OntoSafe	X				X			X		X
POPE	X			X		X				
OntoReg	X		X	X						
BaPrOn	X	X		X	X	X				
PrOnto	X			X				X		X

5 Conclusion

The ideas of agent technology and model-based engineering have shown potential in various prototypical implementations and academic environments. However, they have not yet found a broad acceptance and application in industrial practice. Regarding model-based engineering, a potential lies in formalizing information for a broad vertical and horizontal data integration and interoperability. In this context, the conformance with industrial standards is crucial for a concept's reusability as well as applicability and thus acceptance.

This paper presented a survey on standards and ontologies for the process domain carried out during the first phase of the project BatMAS, which aims at the integration of a system ontology for providing an extensive knowledge base. On the one hand, the knowledge base should be accessed by an agent-based system for batch process automation and on the other hand, it should provide access for various functionalities of a complete automation solution.

Regarding information models for these functionalities, none of the analyzed standards and ontologies alone is sufficient. However, a satisfying solution could be achieved by combining their concepts and ideas. Therefore, further research will be concerned with merging the concepts towards a unifying solution.

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