Relevance and Usage of Semantic Technologies in the Factory of Things

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Abstract. The Factory of Things (FoT) describes the extension of the Internet of Things specific to the production domain. The semantic description of products, processes and plants depicts a basic module of this approach, through which information can be filtered and services can be discovered and orchestrated on demand. The usage of semantic technologies in the context of production can make a valuable contribution towards managing the growing complexity and increasing the flexibility and adaptability of production facilities. This position paper discusses several use cases, which explain the potential advantages of using semantic technologies in the field of production automation. These scenarios cover the interpretation of heterogeneous context data using ontologies, the semantic description of facilities including the respective components (e.g. sensors), and the orchestration of semantically annotated web services to build complex production processes. Based on the described use cases, several scientific issues are discussed with a special focus on semantic interoperability.

1 Introduction

The Internet of Things describes the ubiquitous networking of intelligent everyday objects, which communicate autonomously, exchange information and provide services. The extension of this concept specific to the production domain is referred to as the Factory of Things (FoT) [1]. The FoT includes the extended usage of ubiquitous information and communication technologies in order to reach the networking of entities in the production domain. Based on this networking, all types of information in a production environment can be collected. The resulting information explosion, however, can only be mastered using a context- and knowledge-based provision and processing of data. Furthermore, the different mechatronic capabilities of a production plant, which are encapsulated and represented as services, need to be orchestrated in order to define complex production processes. Therefore, a semantic description of products, processes and production plants is needed.

Semantic technologies allow the formal description of data and support the semantic processing of data by machines, i.e. the interpretation of electronically stored pieces of information with regard to their content and meaning. The formal, explicit representation of knowledge forms the cornerstone of the Semantic Web [2] and includes both the modeling of knowledge and the definition of formal logics, which provide rules to

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draw inferences over the modeled knowledge base. While several semantic modeling approaches for the representation of knowledge with different expressional power exist (e.g. taxonomies, thesauri, topic maps [3]), ontologies depict the most popular and the most powerful approach of explicit knowledge representation. Ontologies, often defined as "'an explicit specification of a conceptualization"' [4], enable the modeling of information as an independent knowledge base. Ontologies consist of three basic structures, namely classes (or concepts), relations and instances. In addition, restrictions, rules and axioms can be defined in order to model complex coherences.

Based on respective description languages like OWL [5] and RDF [6], ontologies facilitate the structured exchange of information among heterogeneous systems, resulting in a semantic interoperability. Another major advantage of ontologies is the possibility to draw inferences over the explicitly modeled knowledge, thereby deriving new knowledge that is contained implicitly in the knowledge base. To this end, a reasoning system is needed, which depicts a piece of software that is able to interpret logically defined facts and axioms and to infer logical consequences.

In the context of the FoT, semantic technologies are essential to ensure a knowledge-based interpretation of information and to facilitate an efficient orchestration of services. This affects the representation of knowledge about products and plants, but also the semantic description of services (Semantic Web Services). The latter one is necessary because the description of a service's interfaces and functionalities via standards like WSDL [7] is of a mere syntactic nature. Similarly, defining an orchestration of services using languages like BPEL [8] happens in a syntactic manner. As a result, there is a semantic gap between the syntactic description of web services and the underlying meaning. On the basis of a semantic annotation, for example using technologies like SAWSDL [9] or OWL-S [10], the meaning of a web service definition can be described in a machine-understandable manner. This additional semantic layer enables the dynamic discovery of semantically described services and the (semi-)automatic orchestration of services to build higher-value services or even production processes.

This position paper presents our opinion about the importance of deploying semantic technologies in smart factory environments and in a future Factory of Things. After a discussion of related work in Section 2, this opinion is supported by several illustrating usage scenarios, some of which have been implemented already in several experimental setups (Section 3). Subsequent to the description of these scenarios, the most important scientific issues that arise from the future usage of semantic technologies in the domain of industrial production are discussed (Section 4). In Section 5, we present our conclusions and discuss opportunities for future work.

2 Related Work

While in several fields of application a central role is assigned to semantic technologies, their usage has not gained acceptance in the field of industrial production yet. The main reasons for that might be the lack of illustrating application examples as well as the complexity of the technical implementation in production environments.

Nevertheless, within the last years more and more research is carried out on the application of semantic technologies to the production domain. Ontologies are frequently

used to build a common interaction model for agents operating the production process [11] [12]. Several approaches have been made to define semantic plant and component models in order to support a condition based maintenance of production plants [13] [14] or flexible reconfiguration of assembly systems [15].
With the evolving usage of service oriented architectures in production systems, the semantic description of services becomes more important. Particularly, within the scope of the SOCRADES project, several concepts for the usage of ontologies in the production domain [16] and for the semantic discovery and orchestration of services to production processes [17] [18] have been developed.
These approaches are closely related to the ideas described in this position paper. However, we describe an industry-related usage scenario, which covers several issues that arise from the special demands resulting from the usage of semantic technologies in the production domain. This scenario will be implemented in a real-world research facility, which is comparable with real manufacturing plants. Furthermore, we integrate several forms of using semantic technologies in production, namely the semantic description of products, processes and plants (overall structure, components, sensors), the semantic interpretation of contextual information (e.g. location, sensor values, state of the plant) and the dynamic discovery and orchestration of semantically described services. Because of the incorporation of these different semantically enriched subsystems based on the formal representation of a vast amount of heterogeneous knowledge sources, our approach is especially interesting for the research aiming at a semantic interoperability.

3 Area of Application and Use Cases

The benefits of applying semantic technologies to the field of production automation are going to be demonstrated by means of different use cases in the *SmartFactory*$^{\mathrm{KL}}$ [21]. The *SmartFactory*$^{\mathrm{KL}}$ is the first vendor-independent research and demonstration facility for the application and evaluation of smart production technologies and includes both research institutes and several partners from industry. It operates a hybrid, modular demonstration plant, which produces colored liquid soap, in a 200 square meters industrial facility. Figure 1 shows a part of the modular soap production plant. In the continuous flow process, the transparent raw soap is heated and mixed with colorant pigments depending on the customer order. The colored soap is filled into bottles, which are then mounted with a dispenser, labeled and commissioned in the discrete production part subsequently. Thereby, all relevant information about the product's production lifecycle is stored on an RFDI tag, which is located directly on the bottle.

One of the central research topics investigated in the scope of the *SmartFactory*$^{\mathrm{KL}}$ is how a transition from function-oriented to service-oriented architectures (SoA) in production can be achieved. To this end, a part of the plant has been converted to a service-oriented control architecture based on WSDL and BPEL. However, as described in Section 1, an additional semantic layer is needed in order to allow a dynamic discovery and efficient (semi-)automatic orchestration of services. Such a service discovery and orchestration based on semantic technologies is planned to be implemented within the scope of the production plant of the *SmartFactory*$^{\mathrm{KL}}$. The semantic description of the production process, the production plant and the corresponding components and devices serves as the basis for this approach. A hierarchical service model is needed to connect the different semantic representations: a production process needs several services to perform certain tasks within the different process steps, while the components and devices of the plant provide their functionality via services. The services themselves must be described semantically as well in order to make a dynamic discovery and (semi-)automatic orchestration possible. Furthermore, the semantic description of the process, the services and the plant, for instance by means of common ontologies, facilitate a semantic interoperability and therefore the improved interaction among heterogeneous subsystems.

Fig. 1. Part of the *SmartFactory*^{KL} production test bed.

Combining these semantic descriptions of subsystems in an intelligent factory environment with the acquisition and interpretation of context information, it is possible to reach a cognitive plant behavior. It is important to clarify that by cognitive plant behavior we do not mean that the plant becomes an autonomous intelligent system which makes decisions by itself. The plant should always be aware of its own state and should be able to make suggestions how to solve a problem instead, thereby supporting the engineer or maintenance worker. This means that the human plays an essential role in our vision of a Factory of Things.

In the soap production scenario, we plan to develop the recognition of defective devices and errors in the production process by interpreting the information provided by an OPC UA [22] server, which collects the data from several programmable logic controllers (PLC) in our system. Having recognized such an incidence, the plant should be able to decide by performing a reasoning over the modeled knowledge whether the product can still be manufactured. This includes the dynamic discovery of field devices

(e.g. pumps) that provide a similar service as the defective device.
In times of ever shorter product lifecycles and an increasing demand for customized product variants, the flexible adaption of the production process becomes essential. Within the scope of the *SmartFactory*$^{\mathrm{KL}}$, we investigate how such a flexible reconfiguration of the production process can be achieved with the help of semantic services. Therefore, we plan to implement an experimental setup demonstrating a semi-automatic orchestration, in which appropriate services are discovered by means of their semantic description and the semantic specification of the new product variant. An engineer can then select the matching services for each production step. The definition of a new production process can be improved significantly by filtering the contemplable services using semantic templates instead of performing a pure syntactic search.

In order to gain further experience in the usage of semantic technologies in the field of production automation, we implemented several use cases, which cover different aspects of the complex scenario of soap production described above.
One demonstrative use case, for instance, deals with the topic of mobile maintenance of production plants and of the corresponding field devices. Thereby, a maintenance worker is supported by a seamless navigation application (Figure 2) running on a mobile device that guides the worker to the faulty field device. To this end, the data of several context sources (e.g. indoor positioning systems) is collected and interpreted. By querying an ontology using this contextual information, explicit knowledge about the present situation can be inferred. This information is then provided to the mobile navigation device, which is able to adapt its user interface depending on the derived situation. In the scope of this usage scenario, we implemented a function library, based on the OWL API 3.0 [19], which can be used to make queries against the respective ontology and to draw inferences independent from the used ontology or reasoner. By the use of this technology, the knowledge about the meaning of different context sources is not hard coded in the source code of the application anymore, but it is explicitly modeled in an extensible knowledge base. As a result, only the ontology needs to be altered if the usage scenario or the environmental conditions (e.g. sensor setup) change.

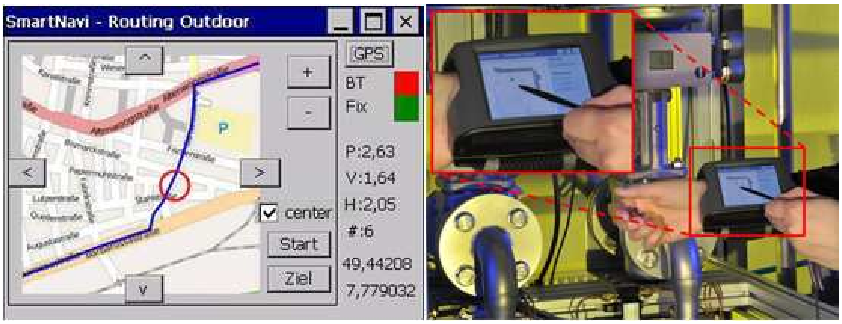

Fig. 2. Ontology-based location-aware maintenance application.

A second use case, which has been implemented in the form of an industry-related experimental setup as depicted in Figure 3, deals with the dynamic discovery of services provided by field devices using semantic annotations. In the process of this demonstrator, pills are filled into bins according to the information stored on the RFID tag located at the bin, i.e. the product itself carries the information about its production order. After the filling process, a camera performs a quality control by counting the number of pills filled to the bin using image recognition. The difference to the approach described by Stephan et al. [20] is that the different field devices included in the production process (e.g. RFID reader devices, inductive and ultrasonic sensors, pneumatic stoppers, camera) are not controlled by a programmable logic controller (PLC) anymore, but they provide services based on WSDL. The orchestration of the services happens via a BPEL engine running on a central server, which controls the production process. In order to facilitate an efficient discovery and binding of the services provided by the different field devices, we annotated the corresponding WSDL files using SAWSDL. The concepts that are referenced by the semantic annotations (e.g. device categories, services, basic operations) are modeled in an OWL ontology. The field devices subscribe automatically using DPWS, which causes their SAWSDL files to be parsed using the SAWSDL4J API and the resulting information about the provided services and operations to be stored as instances in the ontology. These instances are deleted from the ontology as soon as the respective devices unsubscribe again.

Fig. 3. Experimental setup: semantic services provided by field devices.

4 Scientific Issues

Several scientific issues concerning the usage of semantic technologies in the production domain arise from the conceptualization and implementation of the usage scenarios presented in Section 3. The complexity of future intelligent factory environments goes beyond the scope of previous fields of application of semantic technologies in most cases. As a result, it is necessary to investigate which forms of semantic technologies are qualified for the description of products, processes, services and plants. Is the expressiveness of today's ontology languages like OWL sufficient to model the complex, heterogeneous knowledge or should we include additional techniques like rule systems? How can semantically described services be orchestrated to complex production processes in a dynamic manner? The application of semantic technologies to this domain offers a great possibility to identify special requirements for the future improvement of these technologies.

Closely linked to the topic of knowledge representation, the issue of knowledge acquisition is commonly known to be one of the major constraints in the development of knowledge based systems [23]. Thereby, the great challenge lies in identifying appropriate knowledge sources and in developing suitable methods to extract the contained knowledge. Several approaches exist to break this ”‘knowledge acquisition bottleneck”’ [24] [25] [26]. However, in the domain of industrial production, the issues of knowledge acquisition and knowledge update become even more difficult because of the variety of heterogeneous knowledge sources such as industrial standards, manuals, specifications, stocklists or CAD models.

When discussing the usage scenarios described in Section 3, especially the complex soap production process, it becomes apparent that a uniform interaction among the different subsystems like the service orchestration and the control of the facility is important. To this end, common interoperability models are needed, which make the meaning of data understandable for each subsystem. The usage of common semantic models (e.g. an ontology describing the plant and the contained components like field devices or sensors, the semantic description of services, semantic device models) can help to facilitate a semantic interoperability among heterogeneous systems. The central issue is the specification of a common vocabulary for the semantic description of different industrial systems in a vendor-independent manner. For that, commonly agreed standards would have to be defined. As long as such standards do not exist, advanced methodologies for ontology mapping [27] are needed.

In order to make the developed concepts, which deal with the usage of semantic technologies in smart factory environments, applicable to existing industrial systems, it is necessary to examine how such systems can be migrated to new implementations and architectures and how much resources it would take to build new factory systems that incorporate semantic technologies. The discussion of these issues is essential for the success of future research on the usage of semantic technologies in industrial production.

5 Conclusions and Future Work

In this position paper we discussed the relevance of semantic technologies in the vision of a future Factory of Things on the basis of several use cases. We identified the most important scientific issues that arise from the usage of semantic technologies in the domain of industrial production. Apart from the semantic description of products, processes, services and plants, the knowledge acquisition problem depicts a cornerstone of our approach. Furthermore, the usage of semantic technologies for the creation of a semantic interoperability among heterogeneous systems in the production domain offers a highly interesting area for future research. In this context, we are going to investigate different mapping algorithms, but also possibilities to automatically extract synonyms

and similarity relations from thesauri like WordNet [28].
Further scientific issues will be addressed in our future research and in the implementation of an industry-related usage scenario within the scope of the *SmartFactory*$^{\mathrm{KL}}$. In the near future, we are going to evaluate the expressiveness requirements of our processes based on the workflow patterns approach [29] because it is necessary to assess whether standard modeling approaches like BPEL, BPML or OWL-S are qualified to describe complex industrial production processes. Another important topic of future work deals with uncertainty and fuzziness of information, especially sensor values, in intelligent factory environments. To address this issue adequately, we have to consider methods such as probabilistic ontologies [30] [31], ontologies extended by fuzzy description logics [32] or combination with Bayesian networks [33].
In order to make the implemented use cases applicable to industrial production, however, further important issues like practicability, security or real-time capability must be examined. We believe that the usage of semantic technologies in the context of production can make a valuable contribution towards managing the growing complexity and increasing the flexibility and adaptability of production facilities.

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