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Applying Contextualization for Data-Driven Transformation in Manufacturing

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Abstract. Manufacturing is highly distributed and involves a multitude of heterogeneous information sources. In addition, Production systems are increasingly interconnected, hence leading to an increase in heterogeneous data sources. At present, data available from these new type of systems are growing faster than the ability to productively integrate them into engineering and production value chains of companies. Known applications such as predictive maintenance and manufacturing equipment management are currently being continuously optimized. While these applications are designed to help companies manage their manufacturing and engineering data, they only use a fraction of the total potential that can be realized by linking manufacturing and engineering data with other enterprise data. In the future, the context in which the data can be set will play an essential role. A meaningful added value in manufacturing can be achieved only with context specific data. Against this background, this paper presents three main areas of application for contextualizing data (semantics, sensitivity and visualization) and explains these applications with the help of a contextualization architecture. The concept is also evaluated using an industrial example. Furthermore, the paper describes the theoretical background of contextualization and its application in industry. The major challenges of the ability of engineers to adapt their activities and the integration of process knowledge for semantic linking are addressed as well.

Keywords: Contextualization · Manufacturing planning · Semantics

1 Introduction

An increasing number of data sources is leading to larger pools of data being collected in manufacturing for diverse applications (scheduling, quality monitoring, maintenance, new design assumption etc.). The data is then being converted into information that helps users perform their activities. Increasing information implies that users need to find, understand, process and act on additional information. Which leads to increasing efforts and perhaps to frustration, especially for the information discovery

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Published by Springer Nature Switzerland AG 2020
B. Lalic et al. (Eds.): APMS 2020, IFIP AICT 592, pp. 154–161, 2020.
https://doi.org/10.1007/978-3-030-57997-5_19

and usage (e.g. searching relevant information across various tools and databases against the unclear background of responsibilities and rights). At this point, the context of data becomes relevant. Until now, various domains have already largely defined the context [1]. In the information technology (IT) environment context means any kind of information that can be used to characterize the situation of an entity in interaction with other entities. Context can be a single piece of information or a combination of many pieces of information from different sources or at different points in time. For example, a CPS (Cyber-Physical System) interacts with a CPPS (Cyber-Physical Production System). Examples of such contextual information could be location, product identification number, machine identification number, time, energy consumption, etc. From the manufacturing user's point of view, the appropriate situational context must be established (e.g. "I want to know why my bearing is not available at work station three."). From a data processing point of view, the interaction between the entities has to take place (e.g. work station three reports that the bearing is not available and an automated search finds possible solutions based on historical data, the worker has to make a solution respectively "I decide to take the bearing from workstation one, because there is still one available and the station is currently in maintenance mode."). Eventually, a decision can be made on the basis of the respective situation and the data. Hence, contextualization contributes to saving time and efforts involved in carrying out an activity and making decisions. A connection to Industry 4.0 as well as data allocation and contextualization of this data is an ongoing challenge: research gaps are becoming apparent [2]. So far, there are only partial solutions in individual technology domains, but no general industrial approach is apparent [3]. To fill this gap, the research methodology followed is to identify the main aspects of contextualization, develop a suitable architecture to integrate them and evaluate the same with an industrial application. The effective evaluation of the contextualization concept and its future scope are further detailed in this paper.

2 Technological Approach

Contextualization consists of three major aspects which have to be combined: context sensitivity, semantics and visualization. These three aspects are described in detail below:

Context sensitivity is becoming increasingly important to ensure that systems are situation-dependent. By using a knowledge base and linking it with context data, information can be provided to the right user at the right time. According to [4], context-sensitive systems can be divided into four levels of interactivity: active execution, active configuration, passive execution and passive configuration. Active executing systems make independent decisions based on the current context and execute the necessary measures to implement the decision independently. Active configuring systems get to know the user over time and adapt accordingly. Passive executing systems understand the context and, based on this, develop proposals of action for the user, who then decides on the next steps. Passive configuring systems offer the user configuration options depending on the context, allowing the user to influence the system configuration.

Semantics: Production and production planning are highly distributed and involve a multitude of heterogeneous data. Necessary distributed systems and their heterogeneous databases require adequate technical possibilities to present (e.g. production and planning) information in a semantic context, otherwise the interpretation of the information is difficult or impossible. Ontologies have proven to be suitable technologies for modelling these semantic relationships in application and research. In the industrial environment, semantics modelled by ontologies are currently mainly used for semantic searches. Ontologies can be created automatically and manually. Automated ontologies can be created efficiently without human intervention and are thus suitable for large amounts of data, but do not represent the implicit knowledge of engineers. Therefore, the literature recommends creating semi-automated ontologies according to templates such as ISO 15926 "Industrial automation systems and integration—Integration of life cycle data for process plants including oil and gas production facilities". Technically, the trend is towards cloud-based applications based on Semantic Web technologies. Semantic Web offers a good basis for doing this in an enterprise context: [5] for example, presents a concept for the automated creation of an enterprise-wide, semantically linked knowledge base.

Visualization of primary abstract data and the interaction with it is important for the development of modern user interfaces. A widely accepted definition of information visualisation is "The use of computer-supported, interactive, visual representations of abstract data in order to amplify cognition" [6]. Information visualization should help to prepare and visualize abstract data accordingly. Therefore, information visualization also supports the cognitive processes of the user, i.e. all processes related to perception and recognition. The aim is to understand semantically analysed and sensitive data more quickly. This forms the basis for human-centred decision making or at least decision support. In the understanding of manufacturing, the development and planning of complex systems requires visualizations that provide an overview of the complex and extensive models. Visual validation can be performed in immersive (virtual) environments where data/information can be experienced [6].

2.1 Contextualization Approach

Contextualization of data can be seen as a valuable input for various applications along the lifecycle of products. Figure 1 shows how the data can be exchanged across the different phases of product lifecycle by using a contextualization architecture as a backbone. The contextualization architecture, which consists of semantics interconnection, context sensitivity and visualization elements supports the users with relevant data from various phases. For example, a designer can benefit from contextual information about market research. This helps the designer to design a product closer to the market needs. Another example is contextualization of production information with regards to the machines available and their capabilities, which helps production planners to plan future production better.

To illustrate the above approach, a real case from the production of aero engines is presented here: in terms of manufacturing, the efficiency of execution of processes, such as production, assembly, maintenance or quality assurance, is directly related to the availability of up-to date product data. The product data has to be updated,

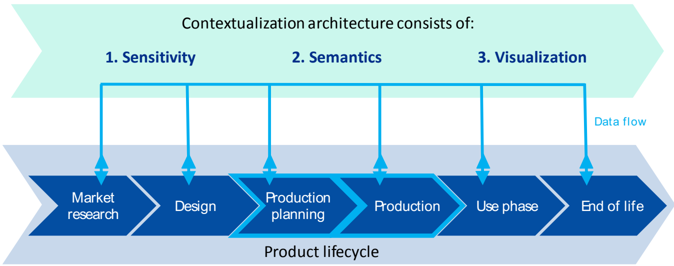

Fig. 1. Contextualization across product lifecycle

available, manageable and traceable throughout the lifecycle. Increasing product variance leads to complexities in production. Complexities in turn cause difficulties in flexible production management, as resources have to be rescheduled and managed across various production programs. This increased complexity creates a challenge for employees who have to be informed and qualified to run the different production programs. In order to support the future of flexible production, it is important to provide the production employees with the workplace of the future equipped with contextualized information.

3 Development of a Contextualization Architecture

The basis for the development of a contextualization architecture is formed by the three essential components "context of origin", "context of processing" and "context of use" (cp. [7]). The "context of origin" is the information about origin of the data. This is linked to the question of "who organized and performed the actions; what were the objects; which features have been measured; what were the reasons or motives for collecting the data; when and where the data were collected; who were the owners; what were the licences used, etc." [7]. The "context of processing" is on a technological level and describes "formats, encryption keys, used pre-processing tools, predicted performance of algorithms etc" [7]. Eventually, the "context of use" describes the "potential domains, potential or known applications, which may use the data or the knowledge extracted from it, potential customers, etc." [7].

The three components are shown on the left hand side in Fig. 2. Furthermore, Fig. 2 shows the application of the components to a general contextualization architecture. Since the processing component is the technological advanced one, it has to be divided into several sub-components to be made applicable. That way, four layers describe the architecture, namely: data layer, semantic middleware layer, context-algorithm layer and the application layer. The application layers host the user interface with which the user interacts with and has contextual information using suitable visualization techniques. Based on the users tasks or request context algorithms pull or push requests to adjacent layers. The request to pull the relevant data is interfaced with the semantic middleware which can be any form of a semantic network which connects various data sources present in the data layer. For example, an ontology web language

(OWL) ontology can be used to connect data and generate triples which can be stored and accessed from the triple stores [8]. It is important to note that heterogeneous data sources can be connected using this method, but structuring of the data sources is required.

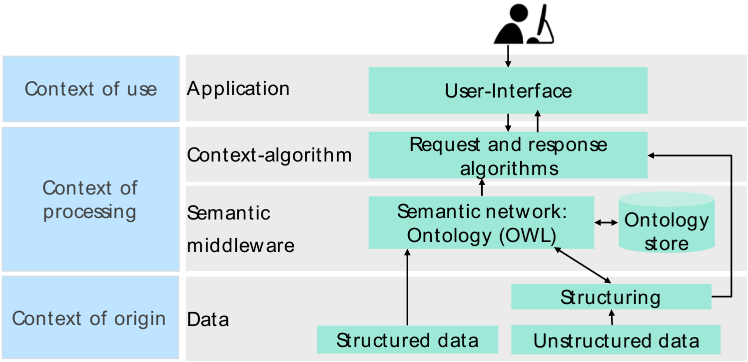

Fig. 2. Contextualization architecture

4 Evaluation of Contextualization in Manufacturing

The evaluation of contextualization is conducted as part of a project called Cockpit 4.0 (funded by the Berlin Senate, the State of Brandenburg and the European Regional Development Fund – ERDF 1.8/03) in which a consortium of Rolls-Royce Germany, Fraunhofer IPK and the BTU Cottbus are working together to address different challenges in the context of digitalization [9]. The aim of the project is to address industrial challenges by assisting in making process data available and interconnected across various processes such as production, assembly, maintenance or quality assurance. Hence, users can work with contextual information to obtain a big picture of the entire lifecycle, track changes, manage, collaborate and interoperate across processes. This helps in improving efficiency of processes, therefore, leading to time and cost savings.

4.1 Goal of the Research

The goal of the project is to develop and study concepts that support the navigation and data analysis in heterogeneous information ecosystems by providing relevant data in context to the current use case activity.

4.2 Methodological Approach

The research approach was based on the Design Science Research Methodology (DSRM) for Information Systems Research [10]. Initially the needs or requirements from the company were derived through a series of workshops with various stakeholders. The needs were then converted to user stories and further grouped and detailed to form use cases. The use cases enabled capturing of the features that needed to be developed. One suitable use case was then selected and developed into a demonstrator with a contextualization architecture. The demonstrator and its user interface were then evaluated by the users.

4.3 Concept

The concept of the demonstrator that was developed together with Rolls-Royce was an assistance system for the assembly of aero engines. The purpose of this demonstrator was to assist a team, called Voice of the Fitter (VoF), in their daily tasks to solve issues faced by the fitters during assembly processes. Examples for the problems occurring are part shortages, tool related issues, non-conformances identified during the assembly and others. As the team had to often search for causes of the problem and solve the problem by searching through various data sources, the assistance system was equipped with contextualization fields to address this situation. The aim was to provide useful information and suggestions, to help speeding up finding and solving problems which occur on the assembly line.

4.4 Implementation

The architecture for the assistance system is based on the contextualization architecture discussed in Sect. 3. It provides context sensitive information to the VoF team from various data sources. The data sources comprise information about the parts of the aero engine, current and historic problems recorded by the team called VoF-cases and reported non-conformances (concessions) associated with a specific engine type. These data sources are generated by different processes along the product lifecycle of the engine. Data from these various sources were connected using an ontology, this represents the connection of data layer with the semantic middleware layer. The ontology is mined for context relevant data through contextualization algorithms. The contextualization algorithms used data fields such as part number and engine type to identify associated information relevant to the user. The algorithms also relied on natural language processing (NLP) to identify datasets with contextually similar and relevant information.

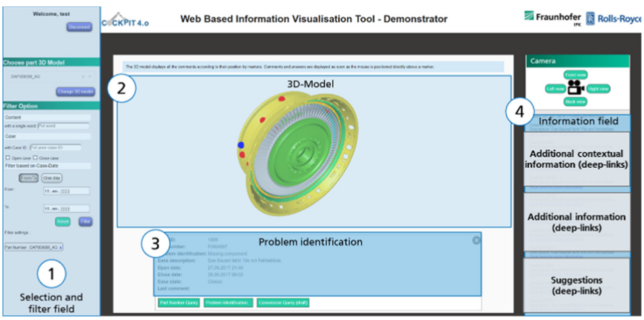

Fig. 3. Front end of assistance system [9] (numbers 1 to 4 are explained in the text below)

The assistance system's front end is shown in Fig. 3. This is a part of the application layer where the user interacts with the system. The first field, indicates the selection and filter field which was designed to provide the team with options to obtain relevant problem information on the part having the problem. The part is displayed in the 3D viewer (2^{nd} pane) this helps the team to visualize the part on which they are planning to solve a problem. The problem identification field (3^{rd} pane) provides information about the problem. The fourth field, is an information field which provides additional context sensitive information (including deep links) from various data sources such as non-conformances, historic problems, similar problems and their solutions, hence, saving research time for the team. This helps in avoiding delays which are extremely critical on the assembly line. The assistance system was evaluated twice with a gap of six months. A VoF team member was briefed about the features available and then was interviewed to receive qualitative feedback and suggestions for improvement. The user then filled the questionnaire presented by F.D Davis to measure perceived usefulness, perceived ease of use, and user acceptance [11]. The results indicated that the user acknowledged the advantages of the system to support daily work. However, highlights scope for improvement with respect to the user interface and additional features to integrate it into the work environment.

5 Conclusion and Potentials for the Future

Data contextualization becomes a base foundation for the design and operation of manufacturing systems. In this paper, the authors have introduced the foundation for data contextualization in the heterogeneous field of data sources in the product and assembly context. The main potentials of data contextualization can be realized in the processes of decision making, knowledge reuse, knowledge transfer and user (planer, fitter, and maintenance personnel) experience. It became clear throughout the execution of this research that new capabilities in designing, planning and executing manufacturing with respect to the collection, identification, interpretation and digital composition of the right or decisive data sets will form a new discipline in manufacturing. This discipline will need competence in manufacturing/engineering process know-how, data analytics, data contextualization, human-machine interaction and IT knowledge. Data contextualization will be a competence that process planners and manufacturing engineers can take on in their professional skill profile, if the digital assistant system configurations offer the appropriate manufacturing problem configurations.

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