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An Approach for a Domain-spanning Collaboration Platform for Decision Support Using Immersive Visualization Techniques in Product Manufacturing

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Abstract -This paper proposes an approach for cross domain collaboration in product development and manufacturing by linking domain specific information models and provides a common visualization by means of Virtual Reality technology. This approach should be considered as work-in-process in an early stage. It should contribute to a decision support platform in which manufacturing alternatives are evaluated regarding criteria of several domains. Therefore information models from process design and product engineering are accessed and linked via items they describe. Linked information models are displayed with stereoscopic visualization technology in order to provide an understandable and yet complete illustration. Users should be able to evaluate manufacturing alternatives and instantly see the impact of modifications in their native and other connected information models. Thereby domain-spanning impacts of manufacturing alternatives can be recognized beforehand and cross-domain communication can be accelerated and improved through mutual understanding of domain experts.

INTRODUCTION

In recent years, manufacturers are addressed with a demand for individualized products leading to a rising number of product variations, which poses new challenges to construction and production processes in various industries. Besides, distinct national and international competition between manufacturers demand close collaboration between all disciplines of an enterprise involved in product and process development as well as value creation in production.

All representatives of the domains involved have their native view on product and process, which drives their priorities in the decision processes. In order to make Pareto-optimal decisions concerning all domains, all participants should be able to communicate their point of view and priorities and in best case be able to regard consequences of their actions in foreign domains. This holistic approach is followed in modern management strategies like balanced scorecard (Kaplan and Norton, 1992). The collaboration of multi-disciplinary teams requires a central, cross-domain information management system in order to have one ‘single point of truth’ for all necessary information to make strategic and operative decisions concerning product, process and value creation. Usually, this is implemented in

Product Lifecycle Management (PLM) systems, which claim to host all product related information throughout the full product lifecycle.
In order to provide decision makers and experts of a specific domain access to a multi-domain stock of information for their decision process in an intuitive and understandable way, we propose a Virtual Reality (VR) based visualization of product and process information to display the information from various domains simultaneously in an understandable and intuitive way.
The concept presented here does not aim to replace any inter-domain discussion; furthermore construction processes should not be automatized. The vision of this approach is to make interconnections between domains transparent to accelerate and ease the coordination between expert groups by extending the information available and visible to indicate junctions of several domains. This should lead to an acceleration of decision processes, improved quality of decision by an extended foundation and thereby benefits from cost reduction potentials. The paper is structured as follows: At first, we introduce the basic concept of our approach in detail. Afterwards we give a brief overview on related work and end with a summary and an outlook on our next steps.

CONCEPT

This section covers fundamental paradigms of our concept. On this foundation, we describe the key elements, succeeded by an introduction of major benefits we aim to achieve. One driving factor for the illustration we propose, are the cognitive processes, which lead to domain specific information models. According to (Stachowiak, 1973) in his fundamental work about General Model Theory the driving factors in modeling are “Pragmatism”, “Reduction” and “Mapping”. The reduction is driven by pragmatism, which determines the selection of relevant elements to be included and eventually emphasized. This basic principle of information models in different domains results in specific models for process-monitoring, construction or economical analysis. In our scenario, all models deal with production processes but they regard different aspects of reality. The reduction of complexity of reality gives the possibility to make decisions from the point of view of a specific domain by regarding domain-specific models. The reductive characteristics of modeling pose risk for not regarding facets of reality sufficiently, which could lead to suboptimal decisions. Therefore, communication between representatives of domains with their specific models is required.
Here our approach is applied: We propose an integrated illustration of (information-) models from several domains in order to give domain experts an insight into interconnections between domain-specific models in order to ease the coordination between domains and create an improved mutual understanding between domain experts from several domains.

Process Modeling

In the process modeling domain various notations have been proposed. We decided to use Petri Nets for describing and modeling processes for several reasons, although our approach can be applied to other modeling notations.
Petri Nets were chosen as they can be used for the specification and verification of processes (Adam et al., 1998). Furthermore they provide the benefit of a mathematical foundation, which makes them

suitable for process analysis and simulation. Petri Nets can deal with issues of manufacturing processes (Desrochers and Al-Jaar, 1995), and they are a quite well-known and well-researched process modeling technique (Reisig, 2010).
Formally, a Petri Net is a directed bipartite graph with two sets of nodes and a set of arcs. A node is either a place or a transition. In the graphical representation circles denote places and boxes denote transitions.
Petri Nets are described by the triple N = *(P, T, F),* where P is the set of places, T the set of transitions and $F \subseteq (P \times T) \cup (T \times P)$ is a flow relation. The numerous proposed Petri Net variants can be subsumed in elementary and high-level Petri Nets.
For our approach the Petri Net must be capable to refer to information models of other domains. We chose high-level Petri Nets, because process objects in high-level Petri Nets consist of net elements described above and process constraints or performance indicators such as cost, time, roles, resources or place capacities. With these process objects we establish an interconnection from the process information model to information models from other domains. We define the process objects following the definition in (Betz et al., 2008). The resources are assigned to the transitions with the mapping function, *mapTranisitonToResources*,

mapTranisitonToResources: $T \rightarrow P(Re)$ *where*

- $Re = \{re_1, \ldots, re_n\}$ is the set of all resources,
- n is the number of resources,
- T is the finite set of transitions and
- $\mathcal{P}(Re)$ is the power set of Re.

Spatial Arrangement of Information

A major component of the approach described here is the integrated visualization of production related information.
The issue of linking information models from several domains has been a topic in research and industry for some time. Concerning product data, STEP (Standard for the Exchange of Product data) has been developed and standardized (PLMS, 2007). Initially we take links between information models for granted though we are aware of challenges when establishing interconnections. The vision to show users the interconnections of elements from several domains raises a major challenge: It might be technically possible to show elements from several domains conjointly, although the mass of information could overburden users with complexity. Hence, the presentation and interaction paradigms should support users to manage the amount of information.
There are several approaches for the visualization of huge numbers of data-elements (Jamieson and Alexandrov, 2007, Chen et al., 2007). In the present case, there is an additional issue of having information sources from several domains. This raises the challenge on the one hand of having a linked information network, on the other hand of having the native domains of the information elements still trackable. Therefore we propose a spatial arrangement of the domain-spanning information model in an immersive, stereoscopic environment. Here, an information space is established retaining the perspective of domains as virtual dimensions in the visualization environment.

Although a visualization of the information space is possible on classic two-dimensional screens, we focus on applying immersive environments as the analogy of domains to virtual dimensions should improve the understandability of the visualized information. The benefit of an immersive visualization compared to a display on a common screen, is evaluated within this approach in the near future. For a proof-of-concept application, which is currently under development, we use the immersive VR environment of LESC (Lifecycle Engineering Solutions Center) consisting of a three surface (front, side and ground) passive stereo projection, in combination with an optical tracking mechanism.
For the visualization of spatially arranged domain-spanning information elements, several prerequisites should be fulfilled. First of all, interconnected content from several domains should be available. Here we focus on process descriptions and associated resources. The visualization concept should be sufficiently generic to be extended on other domains. One way to arrange domain-specific information models in a virtual space would be a cylindrically orientated distribution as indicated in Fig. 1. Domain-model would be visualized on sections of a cylinder. Thereby users could have the area of interest, whether it is a specific domain model, an excerpt of a model or the interconnection between several models in focus by their current point of view. With physical motion, assuming technical conditions like in a Cave Automatic Virtual Environment (CAVE) with several projection screens, users could change their point of view and thereby put different aspects of the information space in focus.

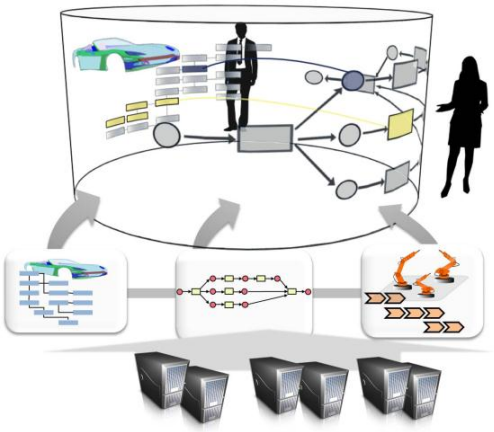

Figure 1. Concept overview

With this kind of information presentation we hope to achieve the following positive effects:
By putting certain aspects of illustrated information in foreground, users still have a reduced mapping of reality to work with, according to general model theory. The disadvantage of fully reduced information can be decreased, as several information models are displayed together without interfering each other fully. The contradiction of understandable presentation and reduction for dealing with complexity can be solved by an immersive presentation. The spatial distribution of models should help users to detect interconnection without being overstrained, as the perspective visualization puts information in background without full reduction. Thereby the user interface should be more understandable as the spatial orientation of humans is followed in the presentation. Users can intuitively alter the domain in focus, by changing their position instead of changing windows or having to use overloaded user-interfaces, like in common applications.

Related Work

In (Betz et al., 2008) a Petri Net model with 3D components, enhanced with parts of an organization model (roles and resources), was proposed. The approach presented here extends this proposal. Elements of the resource view are used to link the process model to elements of the construction domain model.
Connections between different product manufacturing focused models to support several domain experts and their communication has been suggested in (Horváth and Rudas, 2009, Stanev et al., 2009). In

(Horvarth and Rudas, 1998), it was proposed to use Petri Nets for manufacturing processes. To show the impact between the several information models a data exchange between the models is needed. Several papers are addressing this problem (Bianconi, et al., 2006, Wang et al.,1989) on the base of existing data exchange formats.

Interoperability issues between information models of multiple domains, belong to the major challenges in research and industry. As described above, several approaches have been proposed to integrate information models from several domains. State of the art PLM solutions, which provide integrated information focus on data management, whereas the visualization of product and process data follows traditional approaches. Commercial PLM solution vendors apply new technologies for information visualization like VR techniques mainly on the visualization of geometry data like construction models or simulation data (visenso, 2010, IC:IDO VDP, 2010). The visualization of product related metadata is usually not tackled. VR solution providers focus on visualizing geometric information. Generally their products access mostly file-based information in CAx and PLM applications for a VR based visualization.

In general, these approaches with their benefits and disadvantages provide the possibility to apply VR in product manufacturing, though when regarded critically, they do not provide any additional information, which cannot be seen and analyzed in a two-dimensional representation. One critical matter of VR applications in this subject is the overall benefit they provide, meaning what additional information and improvement is provided to justify the price and effort of applying VR, as the content, which is already available and accessible in PLM and CAx systems is visualized in another user interface.

Regarding abstract information visualization in contrast to geometry-based data, there are some applications and paradigms followed. In general, these approaches can be classified as Visual Datamining applications. These applications use human ability for visual pattern recognition to find correlations when computer based algorithms are not applicable.

Some efforts were made to integrate PLM information in VR-based product visualization (IC:IDO VDP, 2010, Choi et al., 2009). These approaches focus on integrating information from several domains, though the focus lies on having some added information to the geometrical illustration of a product or a manufacturing resource.

CONCLUSION

In this paper, we have introduced an approach for an integrated, context-sensitive visualization of Product-Process-Resource (PPR) data applying VR technology. This approach aims to improve mutual understanding between domain experts within the scope of product development. Information models, following the concepts of general model theory are derived for certain tasks and domains. This is in contrast to the demand for a holistic optimization regarding all perspectives in product engineering. For resolving collaboration issues by creating mutual understanding about reality, which is abstracted to models, we propose to use stereoscopic visualization techniques to map the domain-specific perspectives to spatial perspectives in the user interface. Thereby we assume to provide a more understandable and yet more complete illustration of product and production related information models. Our approach is considered to be work-in-process and is introduced to the research community for discussion about general suitability.

The approach presented here puts the process perspective in primary focus. For modeling processes, Petri Nets are used because of their mathematical foundation. Elements in the Petri Net are connected to technical product data without geometric representation, which interconnects the process perspective and product perspective. Currently a proof-of-concept application is under development focusing on product-process information visualization, though the general approach could also be extended to further application domains like Finance or Supply Chain Management.

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