Ontology-based Representation of Time Dependent Uncertainty Information for Parametric Product Data Models

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Abstract: The lack of information about uncertain conditions in manufacturing and the behaviour of load carrying systems still lead to fatal design decisions. Semantic technologies provide the necessary capabilities to link information from different domains along the product lifecycle and enable engineers to cope with uncertainty. This paper presents an overview of existing literature in the fields of semantics in CAD and PLM. We identify future research challenges and present our concept for the integration of uncertainty information in parametric CAD models.

1 INTRODUCTION

A shorter time to market, an increasing degree of product customization and massive cost pressure call for the exploitation of all knowledge available. Semantic technologies and especially ontologies can support the federation of domain specific information in order to make existing knowledge accessible.

Increasing amounts of sensor data from the manufacturing and usage phase of load carrying systems such as landing gears reveal the non-deterministic nature of single parameters and their interaction in large systems. Despite of a shared understanding for the impact of over- and under sizing components Engineers still work with nominal dimensions, fixed margins of safety and tolerance specifications. Uncertainty Data cannot be processed in current CAD-kernels.

The approach presented in this paper introduces the possibility to apply semantic technologies for the representation of processable uncertainty information in the parametric product model. This allows Engineers in the design process a better understanding of the actual conditions during manufacturing and usage. Hence, product development converges to real product lifecycle data.

2 STATE OF THE ART

2.1 Related Literature

Literature in Knowledge-Based Engineering, PLM and domain specific approaches in Computer Aided Engineering discuss possible future applications for Ontologies. In the field of CAD, Ontologies are often used as exchange format for CAD features between different CAD Systems (Altidor, et al., 2011), (Ramya T. Chaparala, 2013), (Ding, 2010), (Lee, Cheon, & Han, 2005), (Tessier & Wang, 2013), (Abdul-Ghafour, Ghodous, & Shariat, 2012), (Song & Han, 2010). Zhong et al. investigate the exchange of semantic assembly information between computer-aided tolerancing systems (Zhong, Qin, Huang, Lu, & Chang, 2014). Andersen et al. propose a domain-specific Ontology for boundary representation models complying ISO 10303-42 (Andersen & Vasilakis, 2007).

Other approaches integrate CAD-systems with different IT-systems along the product lifecycle. Dartigues hands on knowledge stored in CAD data for process planning (Dartigues, Ghodous, Gruninger, Pallez, & Sriram, 2007). Young et al. share knowledge for decision making in the manufacturing process (Young, Gunendran, Cutting-Decelle, & Gruninger, 2007). Alani generates geometric models out of requirement templates (Alani, 2007). Related to this topic, Kuhn presents

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an approach for updating existing templates (Kuhn, Dusch, Ghodous, & Collet, 2012). Assembly process generation based on assembly information is proposed by Zhu (Zhu, Wu, & Fan, 2010).

In contrast, PLM oriented literature supports the interaction of more than two different systems along the product lifecycle. General information models are proposed by Sudarsan and Matsokis (Sudarsan, Fenves, Sriram, & Wang, 2005), (Matsokis & Kiritsis, 2011). Evangelou and Karacapilidis develop an Ontology for multicriteria collaborative decision making (Evangelou & Karacapilidis, 2005). Since different domains often use several ontologies, Zhan presents a mapping methodology in the context of PLM (Zhan, Jayaram, Kim, & Zhu, 2010). Franke investigates the automatic generation of ontologies and a subsequent design rule checking process (Franke, Klein, Schröder, & Thoben, 2011). Anderl et al. distinguish the representation, the presentation and the visualization along the product life cycle (Anderl, Maurer, Rollmann, & Sprenger, 2013). Here, the uncertainty information is attached to the topological elements of the B-rep model.

2.2 Research Challenges

For future research, different challenges can be identified. In the context of Knowledge-Based Engineering, Verhagen claims a stronger standardisation for the development of new methodologies and a shared framework for the assertion of solutions in order to facilitate the exchange and the re-use of research findings (Verhagen, Bermell-Garcia, van Dijk, & Curran, 2012). Looking more detailed into the existing literature about CAD- and PLM-Ontologies, Verhagens observations can be confirmed and extended as follows.

Extending Ontologies by the representation of parameters seems a promising approach for the integration of both B-Rep and Feature-models. Taking into account current standards can be helpful for the transfer of research findings into industry. For CAD applications the upcoming ISO 10303-242 allows new perspectives with its capabilities of representing parameters, features, modelling history and semantic Product and Manufacturing Information (PMI). In the Area of PLM the Product Lifecycle Support library (PLCSlib) supports implementations of ISO 10303-239 with a semantic model for the terms in use.

Attaching Uncertainty Information to parameters represents the next step in the Collaborative Research Centre (SFB) 805 in order to make more information from the manufacturing- and usage-phase exploitable in the development-phase. Especially the connection of time dependent information to parameters allows the avoidance of unpredictable interactions within assemblies.

The automatable acquisition of information along the Product Lifecycle for the successive re-use is maybe the biggest challenge in semantic research today. Extracting and storing multiple parameters for one feature for the instantiation of individuals implies the integration of different applications and data repositories along the Product Lifecycle.

3 METHODOLOGY

Connecting time dependent information about uncertainty to the product model requires the interaction of different technologies. For a common understanding, all relevant notions and technologies are resumed briefly.

To these belongs the notion of uncertainty, the principals for semantic representation and the parametric product model description.

3.1 Uncertainty in Load Carrying Structures

Building up on existing definitions of epistemic and aleatoric uncertainty, the SFB 805 established three categories of uncertainty. With respect to the quality and the quantity of all relevant information, “unknown uncertainty”, “estimated uncertainty” and “stochastic uncertainty” can be distinguished.

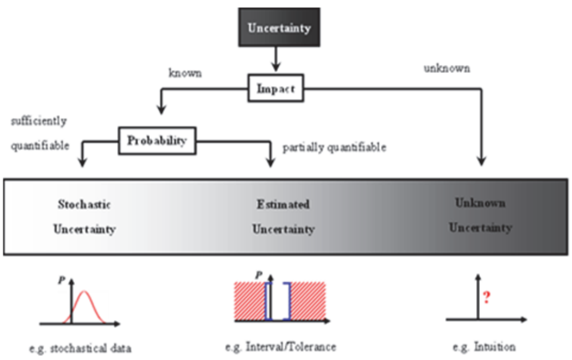

Figure 1: Uncertainty model, compare to (Engelhardt, et al., 2010).

In case of “unknown uncertainty”, the considered product- or process properties are not available or not trustful. For “estimated uncertainty” properties and interdependencies can be described by intervals, tolerances or nominal values. “Stochastic uncertainty” implies a low level of uncertainty so that properties and their interdependencies can be described by frequency distributions (Engelhardt, et al., 2010). One possible representation of uncertainties for data exchange is proposed by Sprenger (Sprenger, 2013).

3.2 Semantic Representation

As in the semantic web, Resource Description Framework (RDF) can be used as data model for web infrastructures between different applications and knowledge bases. RDF uses a triple syntax of subject, predicate and object to formalize and describe relations between resources, such as information or documents.

All resources can be addressed by a namespace dependent Unique Resource Identifier (URI). The Web Ontology Language OWL 2 builds on the capabilities of RDF and extends them. Restrictions like “disjoint with” or “same as” can be expressed by set operations which allow the inference of implicit information, consistency checking and classification.

Unlike in RDF, individuals and classes are supposed to be disjoint in Ontologies. While the terminological box (t-box) contains the description of concepts in a domain, the assertional box (a-box) contains individuals and information about them. In this context individuals are specific CAD models such as assemblies, parts, their composing elements, as well as parameters which are related by constraints.

3.3 Parametric Product Description

Parametric product descriptions are used in parametric CAD systems for hybrid CAD models as well as for generative and accumulative CAD models. Following Anderl and Mendgen, parameters are connected by constraints to each other in parametric product descriptions. Parameters can descend from different domains such as geometry, material or technology as shown in Figure 2.

Constraints can be differentiated in geometric and engineering constraints. Geometric constraints like parallel or horizontal connect geometrical parameters to each other. Engineering constraints define relations between geometrical and non-geometrical parameters. These constraints are functional or logical and can also impact on the topology.

All types of constraints are represented by equations or predicates. Equations are summarized in explicit or implicit equation systems. Solving procedures are sequential for explicit equation systems and simultaneous for implicit equation systems. In order to deduce at least one possible solution, the equation system needs to be determined.

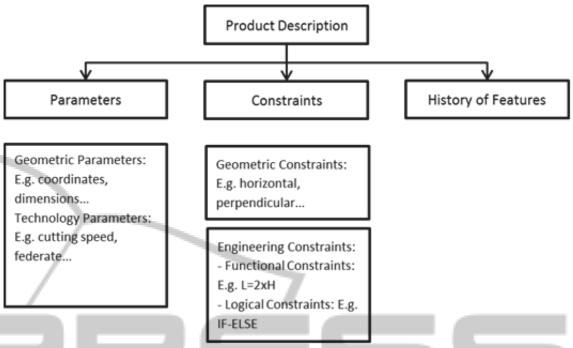

Figure 2: Parametric product description, compare to (Anderl & Mendgen, 1996).

When Constraints are expressed with predicates rule-based solving approaches can be used (Anderl & Mendgen, 1996).

In case of uncertainty, the equation system is underdetermined due to missing parameters or it is overdetermined due to scattered values of distributed parameters. Thus, neither simultaneous nor sequential solving methods can be used. However, rule-based approaches are not restricted by these conditions so that they make it possible to reason about the available information and to reduce the solution space.

4 CONCEPT

The axiom of incomplete information makes ontologies a suitable tool for the exploration of a network of constraints. Incomplete or uncertain information can be used for inferring implicit part properties. For a given part, information about the geometry, topology and engineering constraints are collected on the feature level and the B-Rep-level. As shown in Figure 3, the given information is combined with PLM-information on the part level. To these belong information about manufacturing constraints and information about usage scenarios.

Subsequent reasoning allows constraint solving or indicates inconsistent assumptions. The linking between the CAD model and the corresponding A-Box-Ontology allows returning inferred knowledge on the level of features and the B-Rep.

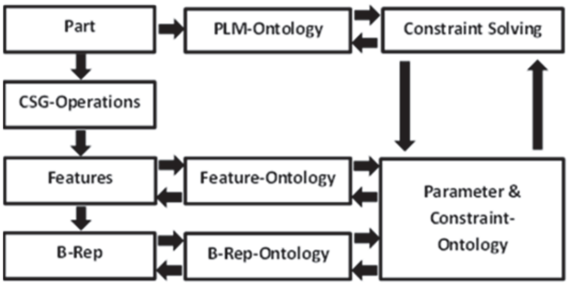

Figure 3: Ontology-based constraint solving for parametric product data.

5 FUTURE WORKS

Future work is supposed to extend the existing framework for the control of uncertainty in different directions:

- The uncertainty information model has to be extended by time dependent properties.
- Strategies for an automated A-Box Ontology generation will be defined.
- Existing feature- and B-Rep-Ontologies will be combined and extended for parametric modelling.
- Existing translation algorithms between feature-Ontologies and features have to be analysed.

6 CONCLUSIONS

Parametric modelling is a well-known standard in CAD-systems. Combining this technology with ontologies opens up the possibility to reason over incomplete information and uncertainty information. We provide an overview of current literature about semantics in CAD and PLM and deduce challenges for future research and development. Our concept for the use of Ontologies in parametric modelling extends our existing research findings on the field of uncertainty representation and proposes new capabilities for the integration of PLM knowledge into CAD. Future research on the properties of probabilistic first-order and description logic opens up possible applications of Ontologies in CAD.

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