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Interpreting the semantics of GD&T specifications of a product for tolerance analysis☆

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HIGHLIGHTS

- STEP models are not capable for interpreting the product data semantics automatically.
- We discussed mapping of STEP models to OWL-based ontology.
- Product's GD&T information mapped from STEP to OWL-based models.
- Implementations have been carried out in Protégé using NIST's OntoSTEP plug-in.
- Ontology based model is used to interpret GD&T semantics for tolerance analysis.

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ABSTRACT

The representation and management of product information in its life cycle require standardized data exchange protocols. ISO 10303, informally known as the Standard for Exchange of Product model data (STEP), is such a standard that has been used widely by the industries. The information language used for STEP is EXPRESS. Even though the EXPRESS language is capable of developing well defined and syntactically correct product models, the semantics of product data are represented implicitly. Hence, it is difficult to interpret the semantics of data for different product life cycle phases for different application domains. OntoSTEP, developed at NIST, provides semantically enriched product models in OWL. In this paper, we would like to present how to interpret the Geometric Dimensioning and Tolerancing (GD&T) specifications in STEP for tolerance analysis by utilizing OntoSTEP. This process requires (1) developing the tolerance-analysis-oriented information model in EXPRESS, (2) combining this model with the ISO 10303 product model, (3) translating the combined model into OWL and (4) defining semantic web rule language to map the GD&T specifications to the specifications needed for the tolerance analysis. This study will help users interpret the GD&T specifications of a product differently as required in different phases of the product's life cycle.

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1. Introduction

The Standard for the Exchange of Product model data (STEP), which is published formally as ISO 10303 [1], has been developed to support the exchange of product data throughout a product's life cycle. STEP enables representing the information required for designing, building and maintaining products. These STEP data models (or schemas) are represented in EXPRESS [2] as a network of concepts: entities and properties of these entities. EXPRESS-based STEP information models are syntactically correct and well defined. The schemas are well suited to represent the syntax of the product model; however, EXPRESS has great difficulty in expressing the explicit data semantics for different application domains at different product life cycle phases. The tolerance specification of a product is possible in STEP (using AP 214 constructs [3]), and in the NIST-led work of AP 242. But unless the semantic representations of those tolerance specifications are explicitly available, a user cannot carry out semantic interpretation of this specification data in areas like tolerance analysis, product manufacturing, assembly or inspection. Recently, semantically enriched STEP product models called OntoSTEP [4,5] were developed at NIST using OWL 2 (Web Ontology Language). These models make it possible to develop a consistent formal model (including both syntactically and semantically correct information) for products that is useful in carrying out the effective computational (both quantitative and qualitative) analyses in different domains of applications as they may be required in different product life cycle phases.

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In this paper, we develop the semantic interpretations of the GD&T (geometric dimension and tolerance) design specifications and use it for the linear, stack-up tolerance analysis. The standard for the representation of GD&T, ASME Y14.5 [6], was selected for our research as it defines how to show nominal dimensions, dimensional and geometric tolerances and symbols for these specifications. The assigned GD&T specifications cause a built-up variation in the final assembly. Because of that reason, in a tolerance analysis, the GD&T specifications have the following varying effects in an assembly: converted geometric tolerance, bonus tolerance, datum feature shift and assembly shift. These variation terms are discussed in detail under Section 3.1.

To develop the semantic interpretations of the GD&T specifications, the development of a tolerance-analysis-oriented information model in EXPRESS (based on the given GD&T specifications) is required first. This embellished GD&T model would then be merged with the GD&T model available in AP 214 [3]. In the next step, this combined STEP schema (model) is translated in OWL 2 using the OntoSTEP plug-in so that the OWL model of the GD&T specifications is now available for further reasoning purposes. The Semantic Web Rule Language (SWRL) [7] rules inferred by the Pellet [8] reasoning tool were chosen to map these GD&T specifications to the specifications needed for the tolerance analysis.

The organization of the paper is as follows: in Section 2, the OntoSTEP and other ontology-based product models are reviewed. In Section 3, the proposed methodology for interpreting the GD&T specifications for tolerance analysis is explained. In Section 4, a case study is given to apply the methodology with examples. The conclusion of this work is explained in Section 5. The paper ends with a conclusion.

2. Review

Different modeling languages are used at different product life cycle stages, for example STEP's EXPRESS may be used at a detailed design stage, while Unified Modeling Language (UML) may be used for initial design stages. It is necessary to consolidate product information created using these different languages to build a coherent knowledge base. The STEP APs are modeled using the EXPRESS (ISO 10303-11) language [2]. EXPRESS was developed for representing product models and providing support to describe the information required for designing, building, and maintaining products. Data models (or schemas) are represented in EXPRESS as a network of concepts (entities), and concepts can have properties (attributes). Entities and attributes are therefore the basic constructs of EXPRESS. The use of EXPRESS is not particularly suited for the integration of STEP data with other STEP or non-STEP product data.

Semantics aims at providing a common meaning to the terms in a particular domain. Lack of explicit semantics and contexts in the content to be shared across PLM applications is a major problem. Making data semantics explicit and context aware and sharable among product life cycle applications is a major challenge. For an evolving organization to function, an information infrastructure that supports well-defined information exchange among the participants is critical. One language that provides such capabilities is OWL (Ontology Web Language) [9]. The OWL representations are generic and OWL is evolving to become the language of the Semantic Web. A comprehensive review on knowledge representation, management and capture of the knowledge in product development processes is given by Chandrasegaran et al. [10]. The role of ontologies for capturing knowledge and supporting semantic interoperability is also highlighted in that study.

There are many studies available in the literatures; they discuss how to develop generic product information models based on STEP information models (i.e., integrated resources and application protocols of STEP as well as newly developed STEP entities) for integrating product design and manufacturing activities. The main objective of these studies is to use STEP product models for communicating between different CAD/CAM (Computer-aided Design and Manufacturing) systems. However, these studies do not provide any interpretation mechanisms that may help understand the semantics of product data in different applications or at different stages of the product life cycle. As an example, Gu and Chan [11] developed a generic product modeling system based on STEP product models to support data exchange between different computer based manufacturing systems. Zha and Du [12] also developed a STEP based generic product information model for the integration of the following applications: product design, assembly design, assemblability evaluation, assembly sequence evaluation and assembly planning.

The number of data exchange standards is also increased due to the ubiquitous need of electronic data exchange between applications used in a product life cycle. Gielingh [13] discussed many issues related to these data exchange standards and the industry adaption of these standards. The most important one is that there are wide varieties in information requirements of different product model representations for the application programs, and the data exchange standards could not represent all of them under a single model. Also, it has been emphasized that the semantics of product information for different disciplines (i.e. different views of product data) cannot be interpreted successfully.

Burkett [14] developed a product data markup language to integrate the information requirements of different application systems by using XML. He utilized STEP to create an integrated information model as a master model and then any necessary product data for a particular application is mapped in to an XML file. The XML file represents a particular application view and carries the necessary semantics. However, it is not possible to infer the semantics of the product data for any other application view automatically by computers in this method.

Integration of different application systems is highly dependent on capturing the semantics of the product information. It is not just a simple data exchange of bits. For example, Lee [15] suggested integrating CAD and CAE systems by creating all possible geometric models for both CAD and CAE simultaneously under a master model. By this method, the idealization of the geometric features or detailing of the analysis features can be achieved directly. However, the number of required geometric models might increase drastically based on the different applications.

Since this paper is based on NIST's OntoSTEP [4] work, it is necessary to review briefly the details of OntoSTEP to understand the proposed methodology. OntoSTEP was developed to provide semantic product models that include geometry, function and behavior information. In OntoSTEP, the geometry information is defined by the STEP models whereas the function and behavior information are defined by NIST's Core Product Model (CPM) [16] and the Open Assembly Model (OAM) [17]. The steps required to develop the OntoSTEP-based product model are given in Fig. 1. First, the EXPRESS model of a STEP application protocol (the implementable portion of STEP) is translated into OWL 2 via the OntoSTEP plug-in [5], and the OWL schema of the STEP AP is created in Protégé [18]. In the second step, the STEP file, which includes the physical product data that is encoded with respect to the STEP AP, is translated into the OWL file. In the third step, the ontology representation of the CPM/OAM model [19] is merged into the OntoSTEP ontology to represent the function and behavior information for products. For details regarding the Fig. 1, please refer to [4].

In the literature, there are other relevant studies [20–23] that focus on ontology-based product models to capture the semantics of the product data. Rezgui et al. [20] highlighted the limitations of data integration in the construction industry when developing and deploying data exchange standards like STEP. They suggested a three-layer ontological architecture to overcome these limitations: (1) the abstract core concepts are defined at the highest level;

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