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Product modeling for multidisciplinary collaborative design

Abstract The paper analyzes characteristics of multidisciplinary collaborative design (MCD) of product and proposes a new MCD-oriented product information model (MCDPM) that integrates physical structure, design semantic and collaboration management data. Better understanding and coordination among the different disciplines can be achieved through the multi-level relations at the semantic level, structure level, and management level. An extended object-oriented method is introduced to represent the MCDPM. As a component and its attributes are all defined recursively in class form, the model can be continually extended and has good modularity, flexibility, and evolution ability. The class inheritance methods in network environment, the concept of discipline view model (DVM) and the method generating the DVM are given. The coordination and consistency maintenance among multiple DVMs is discussed.

Keywords Collaborative design · Multidisciplinary design · Multi views model · Product modeling

1 Introduction

A complicated mechanical product has generally various functions. It is required that the designers in different disciplines collaboratively work to improve the product quality and shorten the development cycle. The designers in different disciplines observe the same product object from different views. The purpose of effectively supporting the cooperation of multiple disciplines and maintaining their consistency makes it necessary to exchange, share, understand, and coordinate the product information among them. Thus, product modeling for MCD is the foundation for building a design system supporting the MCD.

Product modeling mainly involves model content, model representation and model management, etc., which are interpreted as follows.

The model content is concerned about the information involved in the product design process. Product design is an iterative synthesis-analysis process through requirement-function-behavior (technical principle)-physical entity mapping transformation [1]. Axiom design theory also considers that design is the mapping process from the function domain to the physical domain. As shown in Fig. 1, the X-axis represents the mapping among different design domains, the Y-axis represents the decomposition levels of objects from abstracts to details, and design involves one bi-directional mapping process [2]. The physical structure is the final result of product design, but product design begins at the function requirements, and ends at the satisfactions of the function requirements. Function, behavior, technology principle, and so on reflect the semantic information of product design, and the physical structure is the result of the semantic reasoning; contrarily, the behavior effect can be obtained by the structure analysis, and the function evaluation can be made by behavior effect. Thus, besides the physical structure data, the semantic information is also very important to enhance the design understanding and coordination among the different disciplines [3]. The well-known product models mainly include the geometry model and feature model. The geometry model mainly describes the geometric information of the product (such as geometry, topology, dimension, and so on) and is usually used for product information sharing and visualization in collaborative design [4], but it does not consider the semantic information of product design. The feature model constructs the product model using the application-oriented feature element that contains not only geometry and topology information but also semantic information of...
geometry entity. However, the feature model mainly focuses on the integration of design and manufacture, and its semantic information mainly expresses the required manufacture information and does not contain the semantic information of product design [5]. In [6], a feature-based collaborative design system is introduced in which the features of a part model can be classified into general feature, collaboration feature, design feature, manufacturing feature, shape feature, process feature, precision feature, and material feature. In [7], a semantic modeling extension (SME) system is put forward. After creating a graphic form using 3D CAD, a designer interactively adds interpretation objects to the graphic form, such as function and behavior, etc, namely adds designer’s intents to the graphic form to generate the cognitive model. Because function and behavior are added only after physical structure has been generated, SME isn’t in accordance with the design synthesis process.

The model representation is concerned about the description and computerization of the model contents. In [8], a set of generic definitions of functional representation, behavior representation and artifact representation are given, but they don’t involve the computerization of the model. The object-oriented method is a common method to represent the product model. In [9], the product model extends traditional OOP and the design objects can be defined recursively without a pre-defined granularity, as a result, the model is implemented as a layered scheme and has good flexibility. In [10], a class feature concept is presented; product modeling libraries are described as class features; a class at a remote location can be used for defining a new class feature at the local site, but the class feature doesn’t contain the semantic information of product design. The component technology based on DCOM or CORBA is another common method to represent the product model. In [11], the models or other software applications are encapsulated in CORBA-based components. Components interact with other components by reciprocal service calls. The services constitute the interface of components and describe what each component can provide. However, the relations among these components are predefined, which don’t satisfy the requirements of dynamic design changes. Besides, the component technology emphasizes on reuse, and exports the results according to request. Using this method, the client can only obtain output results from the component rather than inherit and expand the component, so that the flexibility of product modeling is weak. The product data exchange standard STEP [12] established by ISO defines the data expressing and exchanging form of product life cycle, but mainly emphasizes longitudinal integration of the different stages of product life cycle and does not support expressing product information about the purpose, function, behavior, and so on [7]. In [13], the product model for MCD is expressed in STEP, but it doesn’t better express the function and behavior information. An integrated model to support distributed collaborative design is proposed in [14], which mainly comprises a semantically-rich, object-oriented database that forms the basis for shared design decisions; however, an integrated model isn’t suitable for MCD because the different disciplines observe the product model from different views and differ in the concerns of the model data each other.

The model management is concerned about the maintenance and management of the model data during the model evolves. In [15], constraints are used to represent engineering requirements. Solving these constraints results in spaces of feasible values of design variables. Such spaces improve efficiency through avoiding artificial conflicts, enhance change management, and support for collaboration design. However, the research only considers numeric type constraints and doesn’t involve other type constraints. In [16], design information is stored as wrapped objects to realize the seamless integration with a CAD system and an object-oriented database (OODB) via an interfacing executable. Through version and configuration management, the alteration in the CAD would automatically update design information to maintain the consistency among the designers. In [17], the coordination among various actors is realized by defining a common repository for knowledge management in a collaborative design situation. In these researches, a common product database is modeled at some location and is shared by many designers located at different places. In MCD, the

![Fig. 1 Axiom design theory](image-url)