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Product modeling framework based on interaction feature pair[☆]

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HIGHLIGHTS

- The framework can make parts pre-interact with each other at part modeling stage.
- It can integrate more design activities and support different modeling approaches.
- It relies on an interaction feature pair (IFP) that can be constructed mathematically.
- An IFP incorporates more information, especially the behavioral information.

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ABSTRACT

Designing products effectively and efficiently is of great significance. However, currently part models are usually created without knowing how they will interact with other parts, leading to gaps between part modeling and assembly modeling and between other applications, and to tedious and redundant labor. This paper proposes a novel product modeling framework to address the problems. The framework is different from current product modeling systems from two aspects. On the architecture level, a new module based on a concept of interaction feature pair (IFP) is developed. An IFP incorporates information of interaction type, related feature pairs and behavioral information that fulfill the interactions. The new module can model the structure of IFPs mathematically through operators and functions defined in a space spanned from six basic IFPs. It can also utilize the constituent elements of an IFP as state variables to form behavior models for the IFP. On the process level, the IFP-based framework can support both bottom-up and top-down approaches, and integrate part modeling and assembly modeling together by changing the workflows. Concretely, IFPs will be embedded into part models at part modeling stage to make them pre-interact with each other, and at assembly modeling stage, parts will be assembled by instantiating the embedded IFPs instead of specifying mating constraints, thus reducing the tedious and redundant labor. Incorporating knowledge of different domains, IFPs can also be developed to integrate more applications together. The implementation of the framework is demonstrated through a prototype system.

1. Introduction

The demand for high-quality and low-cost products with a short development time for the dynamic global market has forced researchers and industries to focus on various effective product development strategies, such as computer-integrated manufacturing and concurrent engineering. The success of these strategies depends on product modeling, which is recognized as one of the key factors for industrial competitiveness [1]. In Computer-Aided Design (CAD), product modeling refers to both part modeling and assembly modeling [2], and the relationships between them in most current (bottom-up) CAD systems can be generalized as: parts are modeled in the part modeling environment first as a collection of surfaces, and then are input into the assembly modeling environment to form an assembly model through applying mating constraints on geometric entities [3,4]. Based on the assembly model, analysis and evaluation work such as assembly sequence planning, etc. can be implemented (illustrated in Fig. 1).

In this product modeling paradigm, when creating a part model, the designer knows how it will interact with other parts; however, this information is not stored with the part model [3], i.e., at part modeling stage, the expected potential interactions of the part with other parts are rarely formalized and incorporated into it. This can be abstracted in Fig. 2(a), in which a shaft and a gear are going to be assembled according to an interaction

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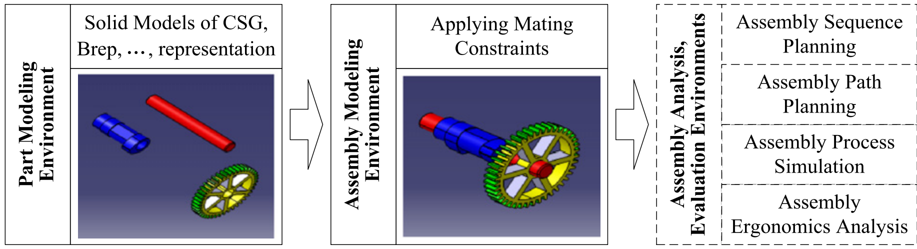
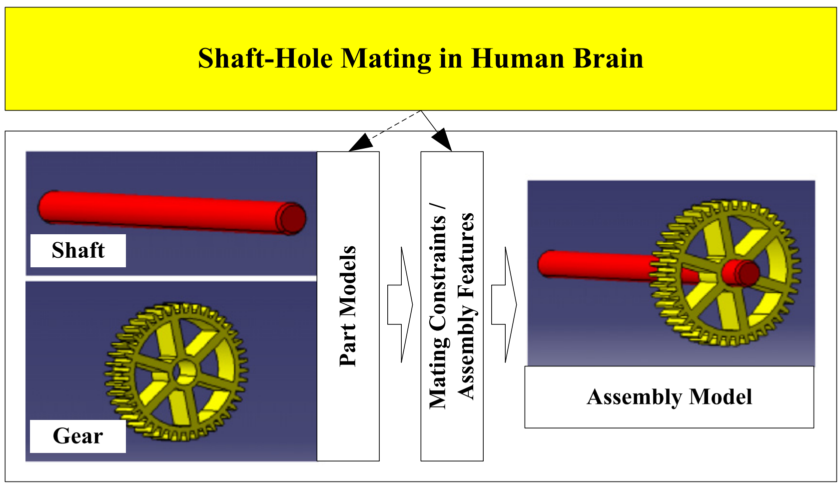
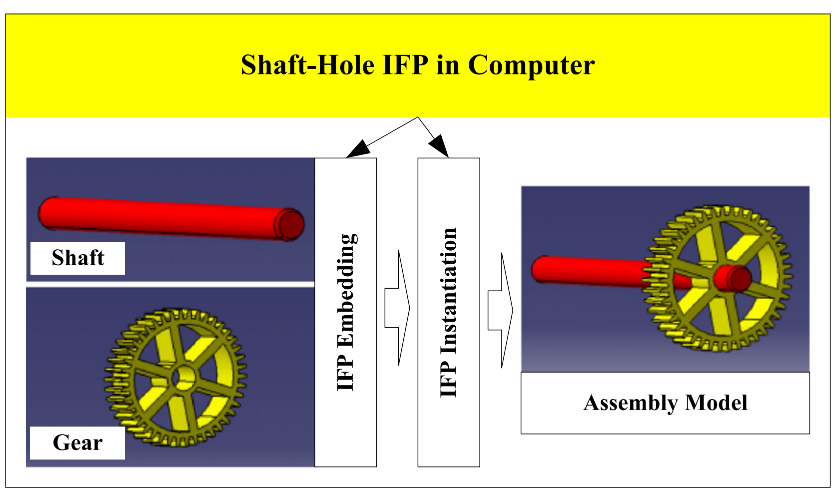


Fig. 1. Current bottom-up CAD systems and their relationships.



(a) Current product modeling strategy.



(b) The proposed product modeling method based on IFPs.

Fig. 2. The difference between the current and the IFP-based product modeling strategies.

pattern "Shaft–Hole Mating"; stored in the human brain, the pattern cannot be directly integrated into the part models at part modeling stage (the dashed arrow in the figure); at assembly modeling stage, mating constraints or assembly features capturing the pattern will be applied to make them interact with each other (the solid arrow in the figure). However, this is usually done manually in industrial applications, though feature recognition technologies (e.g. [5,6]) can be developed to change this situation. The realization of interactions between parts in downstream applications such as assembly planning and simulation is similar to this. Specifying interactions between parts discipline by discipline raises two severe problems: (1) there is little integration between part models and assembly models, nor between assembly models used in analysis and evaluation activities [2]; (2) determining interactions between parts, such as applying mating constraints on geometric entities, is tedious and error-prone, especially for large assemblies [3].

Endowing a part with the ability of knowing its potential interactions with other parts at part modeling stage may be a natural choice to alleviate the problems. For consistency's sake, "interaction" here is referred as an effect that can establish a kind of relationship between part models. For example, applying mating constraints between parts and calculating a path to mate parts enable interactions between them. "Interaction" is related to three aspects: (1) the interaction relationships between parts; (2) the interaction region where the relationships occur; (3) the