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A CAD–CAE integration approach using feature-based multi-resolution and multi-abstraction modelling techniques

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Abstract

In spite of the widespread use of CAD systems for design and CAE systems for analysis, the two processes are not well integrated because CAD and CAE models inherently use different types of geometric models and there currently exists no generic, unified model that allows both design and analysis information to be specified and shared. In this paper, a new approach called the CAD/CAE-integrated approach is proposed and implemented by a feature-based non-manifold modelling system. The system creates and manipulates a single master model containing different types of all of the geometric models required for CAD and CAE. Both a solid model (for CAD) and a non-manifold model (for CAE) are immediately extracted from the master model through a selection process. If a design change is required, the master model is modified by the feature modelling capabilities of the system. As a result, the design and analysis models are modified simultaneously and maintained consistently. This system also supports feature-based multi-resolution and multi-abstraction modelling capabilities providing the CAD model at different levels of detail and the CAE model at various levels of abstraction.

Keywords: Integration of CAD and CAE; Multi-resolution; Level of detail; Level of abstraction; Feature; Solid modelling; Non-manifold topology; Geometric modelling

1. Introduction

Recently, three-dimensional CAD systems based on feature-based solid modelling techniques have been widely used for product design. At the same time, engineering analysis using CAE systems has been an integral part of product design. In order to improve the product design process, it is crucial to integrate CAD and CAE closely, and ideally, seamlessly [1,15,19]. Whether CAD and CAE applications can be closely integrated and automated depends upon the following factors: the scale, scope, and purpose of the CAE analysis; the nature and dimensionality of the CAD model; and the amount of detail required for the CAE application. Currently, there are two approaches to CAD and CAE integration: CAD-centric and CAE-centric [19].

In the CAD-centric process, the design is captured initially on a CAD system and an iterative design process requiring periodic analyses and design changes is used to improve or refine the design. This method has been widely adopted in the current design process. Finite element analysis (FEA) is one of the most popular CAE methods. Unfortunately, design models created by CAD systems are often unsuitable for FEA needs. As shown in Fig. 1, FEA systems usually require abstracted model while CAD systems frequently provide detailed solid models. Therefore, as shown in Fig. 2, an appropriate idealization process including detail removal and dimensional reduction is indispensable for FEA-specific analysis models [1,2,50]. This idealization task is a significant obstacle to CAD and CAE integration as it is a non-intuitive and time-consuming job. To solve this problem, there have been many research efforts to automate the abstraction process, for instance, using automated medial axis transformation (MAT) of solid models [3,11,40,41]. However, at present, only limited automated capabilities exist, and these require improvement.

In the CAE-centric process, engineering analyses are performed initially to define and refine a design concept using idealized analysis models before establishing

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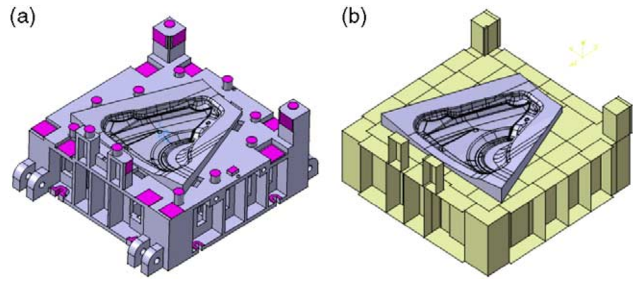

Fig. 1. Geometric models in CAD and CAE systems: (a) a detailed design model; and (b) an abstracted analysis model.

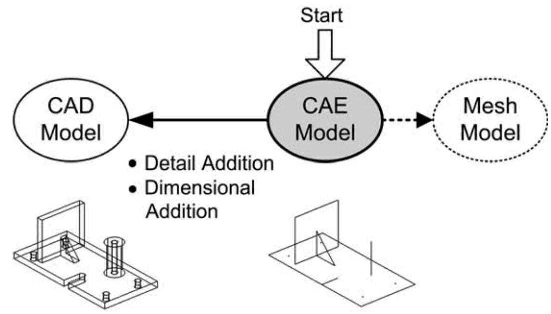

Fig. 3. The CAE-centric approach.

the CAD product model. As shown in Fig. 3, the design model is generated by adding detail and dimensional information to the analysis model. This approach of adding detail and dimensionality after analysis is contrasted to the CAD-centric approach that requires de-featuring of CAD details for FEA-specific geometry and analysis models. Automated and semi-automated procedures are desirable for this CAE-centric approach. An automated 'solid-on-demand' transformation capability is required to electronically send the CAE model to the CAD system. Otherwise, design personnel create the solid geometry model from scratch.

Both of these approaches require duplicate efforts to create and consistently maintain two different models for one product. Lack of automated transformation tools between design and analysis models often leads to the creation of the other type of model from scratch. This manual transformation is a significant bottleneck in CAD–CAE integration. In addition, in engineering analyses, it is often required to change the level of detail (LOD) and/or the level of abstraction (LOA) of the analysis model [1,18]. Whenever the LOD or LOA is altered, the transformation process must be carried out again. As a solution to these problems, a common modelling environment and bi-directional CAD–CAE integration has been addressed [2,19]. The system allows the CAD system to generate analysis models automatically, and allows the CAE system to modify the part geometry automatically and to conduct new analyses. The entire process is iterated until the specified quality measurement criteria have been met.

To achieve this goal, we proposed a new method called the CAD/CAE-integrated approach to provide a unified and concurrent modelling environment for seamless CAD–CAE integration. Fig. 4 shows the data flow in this approach. The underlying technologies for this approach are design-by-feature, non-manifold topological (NMT) modelling, multi-resolution solid modelling, and multi-abstraction NMT modelling, which is newly proposed in this paper. In this approach, different types of geometric models are simultaneously created for design and analysis for each feature modelling operation. These are merged into a part master model, which is an NMT model called a merged set [13]. Solid models at various LODs can be immediately extracted from the master model. Moreover, for a specific LOD, abstracted NMT models at various LOAs can be rapidly extracted from the master model and transferred to CAE systems. For design changes, modification of the master model results in the simultaneous and consistent modification of the design and analysis models.

The remainder of the paper is organized as follows. Section 2 first reviews the detailed CAD–CAE or CAE–CAD transformation processes for each integration approach, and then surveys the related work on the component technologies used in these processes. Section 3 describes the overall process and the system architecture in the CAD/CAE-integrated approach, and Section 4 describes the data structure for part master models in the feature-based NMT modelling system. Section 5 introduces the idealization process using multi-resolution and multi-abstraction

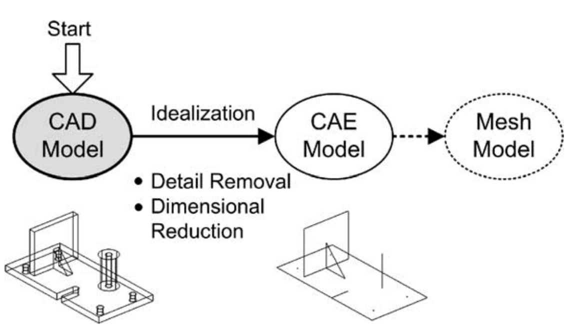

Fig. 2. The CAD-centric approach to CAD and CAE integration.

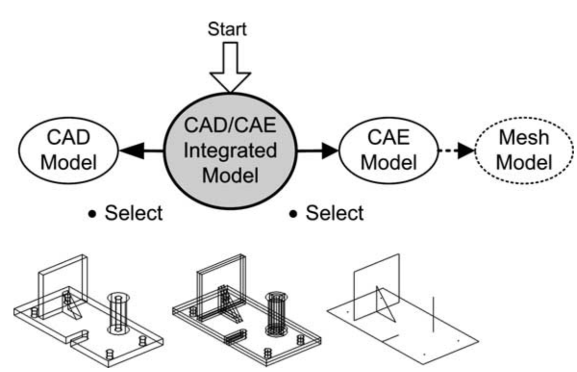

Fig. 4. The CAD/CAE-integrated approach proposed in this paper.