Computers in Industry 75 (2016) 67–79

Contents lists available at ScienceDirect

Computers in Industry

journal homepage: www.elsevier.com/locate/compind

An approach to automatic adaptation of assembly models

Wanbin Pan[a,b], Shuming Gao[a,*], Xiang Chen[a]

[a] State Key Laboratory of CAD&CG, Zhejiang University, Hangzhou, PR China
[b] School of Media and Design, Hangzhou Dianzi Univesity, Hangzhou, PR China

ARTICLE INFO

Article history:
Received 28 October 2014
Received in revised form 21 May 2015
Accepted 16 June 2015
Available online 4 July 2015

Keywords:
Assembly model adaptation
Shape adaptation
Kinematic semantics adaptation

ABSTRACT

Adaptation plays a fundamental role in case-based design. However, after decades of efforts, automatic adaptation is still an open issue. In works of case-based design, a designer usually chooses a start-up product model (a candidate model) of moderate complexity based on a query model possessing primary new design requirements (kinematic semantics and geometry), then achieves the target design by adapting the candidate model according to the new design requirements and human interventions are often indispensable. To smartly adapt the candidate model to fit the new design requirements, a novel approach to automatic adaptation of assembly models is proposed in this paper. First, in order to effectively identify the corresponding links and interfaces between two non-preregistered assembly models as relevant elements, an attributed kinematic graph is put forward and adopted. Second, based on the attributed kinematic graph, the kinematic semantics of the candidate model is automatically adapted to that of the query model. Third, through performing interface layout transferring, the geometry of the candidate model is automatically adapted to that of the query model based on the corresponding links and interfaces. A prototype system is also implemented to verify the effectiveness of the proposed approach.

1. Introduction

Recently, in order to effectively reuse models to improve the efficiency and quality of product design, case-based design (CBD) attracts more and more attention [1–5], which views product model design as a process of retrieving one candidate model and adapts it to make it fit the new design requirements. Over the past decades, retrieval methods are well studied [2,3,5–11], while the works about adaptation are still immature and often human-dependent [3,12]. Since the adaptation process is an essential step in CBD while usually tedious and time-consuming, especially during routine designs, to free the designers from this unnecessary burden, automatic product model adaptation is very important for improving the efficiency of CBD.

At present, the mainstream approaches for automatic product model adaptation fall broadly into two types: parametric design approach and combination/substitution approach. The parametric design approach mainly adopts parametric method to embed the domain knowledge into product models, and uses parameter adjustment to satisfy new design requirements [13–15]. As for the combination/substitution approach, elementary units/function units are employed to achieve target solution based on elementary unit combination or substitution [16,17].

As pointed out by [9,18], a designer in the early design stage often has just primary new design requirements, making it difficult to formulate a complete model. Therefore, it would be very helpful if the designer can create a rough query model indicating the requirements and use it to find some similar previous models with more details. This is because the previous models found, called candidate models hereafter, can inspire the designer to conduct further design and save the designer's time by reusing them in the detailed design stage. In order to effectively reuse the candidate model, one key technical issue is how to make the candidate model adapt to the more abstract query model indicating the requirements, i.e. how to effectively modify the more detailed candidate model to make it meet the primary new design requirements indicated by the abstract query model.

Generally, an ideal adaptation approach should be automatic, independent of domain knowledge library and low demand on shape similarity so as to make the adaptation approach more efficient, general and flexible. Thus, the mainstream automatic product model adaptation approaches are still far from what industries expect. For example, the parametric design approaches usually require the candidate model nearly to have the consistent geometry shapes with the new requirement/the query model. And

* Corresponding author.
E-mail addresses: panwanbin@hdu.edu.cn (W. Pan), smgao@cad.zju.edu.cn (S. Gao).

http://dx.doi.org/10.1016/j.compind.2015.06.005
0166-3615/

the combination/substitution approaches often need domain knowledge libraries. Furthermore, the domain knowledge is usually not provided for most of the models, which makes the mainstream approaches tend to be failed in automation.

In this paper, a new approach to automatic adaptation of assembly models is presented with a view to overcoming the above mentioned problems with automatic product model adaptation. The objective of the proposed approach is to make the assembly model adaptation automatic, independent of domain knowledge library and low demand on shape similarity. The inputs of the approach are two assembly models without having been pre-registered: a query model and a candidate model. The query model, indicating the primary new design requirements through its rough shape and its kinematic semantics, is a simple model. The candidate model is searched from a model library according to the query model, whose overall shape is similar to that of the query model but having more details and more complex kinematic semantics. Considering that the kinematic semantics is the intrinsic characteristic of an assembly model, the basic idea of the proposed approach is to realize automatic kinematic semantics adaptation of the candidate mode first, and then automatically achieve the geometry adaptation based on the result of the kinematic semantics adaptation.

The rest of the paper is organized as follows. After briefly introducing related works in Section 2, some concepts and the overview of the approach are described in Section 3. In Section 4, we identify the corresponding links and interfaces. Subsequently, the kinematic semantics adaptation and the geometry adaptation are respectively presented in Sections 5 and 6. Implementation and comparisons are introduced in Section 7. Finally, we present the conclusion and our further works in Section 8.

2. Related works

As there are a few works dedicated to automatic case adaptation particularly for automatic model adaptation, the works that we have surveyed are surrounding the two challenges for achieving automatic concept/geometry adaptation in mechanical engineering domain [3]: identifying correspondence between the two given cases/models and transferring new design requirements via the correspondence.

2.1. Identification of the correspondence between two given cases/models

2.1.1. Concept correspondence

Identifying the conceptual correspondence, between a library case and an input target problem/a query case, is often performed in the process of case retrieval in Case-Based Reasoning [2,3,5,6,10,19,20]. And, there are so many variations of case retrival methods, such as weight distribution method [21], hybrid similarity measure method [22] and etc. Recently, ontology-based technology becomes a hot research topic for case retrieval in CBR. For example, Guo et al. [11] and Bejarano et al. [6] integrate ontology into CBR system, which make their proposed methods have enough semantic understanding ability on engineering design. However, concept correspondence is yet to provide direct geometry correspondence between two matched cases.

2.1.2. Geometry correspondence:

Generally, finding the common local areas between models is the focus of partial retrieval [8,23–25] and common design structure discovery [26,27] in engineering areas. For example, Bai et al.[8] present a hierarchical way to support multi-level partial retrieval by defining the criteria for reusable subpart of models. Besides, You et al. [23] and Tao et al. [25] also present two retrieval methods respectively based on the local feature correspondence via IMC detection and local surface region decomposition. Additionally, Ma et al. [26] present a common design structure discovery method based on face adjacency graph which also can be used for finding feature correspondence. Besides, some global content-based retrieval methods also provide geometry correspondence implicitly or explicitly [28–33]. For example, both of the methods based on DBMS [31] and hierarchical representation for B-rep model retrieval [29] provide a level-of-detail geometric area correspondence between a query model and a candidate model. However, the correspondences brought by these partial retrieval methods are usually coarse and/or affected by geometric detail differences.

Currently, the assembly model retrieval methods usually provide high-level geometry correspondence. For example, Deshmukh et al. [7] present a mating graph to describe the relationship among the parts of an assembly model, and part correspondence between two assembly models can be obtained based on isomorphism sub-graph identification. Wu et al. [33] present a retrieval method based on product spatial layout/structure matching, where two parts has similar attributes and spatial position is deemed as a pair of corresponding parts. Additionally, Zhang et al. [27] present a generic face adjacency graph for discovering the common design structure from assembly models and bringing part correspondence as well. Based on the hierarchical structure of each assembly [34], Chen et al. [9] present a flexible assembly model retrieval method, which can bring geometry correspondence between two assembly models in topology. However, their corresponding result is more or less subjective [27] since the hierarchical structure is often flexible.

2.2. Transferring of new design requirements

Watson et al. [2] describe a survey of adaptation in CBD where they summarize that adaptation in design can be carried out in four types of approaches: human intervention, knowledge-based adaptation, case-combination adaptation and combinations of the above approaches. Avramenko et al. [12] summarize two approaches-structural adaptation and derivational adaptation, and various adaptation techniques ranging from no adaptation to case-based substitution. As we know, the kinematic semantics design is one of the most creative and important stages in mechanical design [35]. And the mainstream adaptation method for kinematic semantics design is function element synthesis [36–40], which provides a number of optional combinations of new mechanisms satisfying new design requirements. However, each function element is usually defined in advance based on domain knowledge and used with the support of a specific knowledge library.

Totally or partially, some works achieve automatic product model adaptation aided with domain knowledge. For example, Hua et al. [41] describe a prototype design system called case adaptation by dimensionality reasoning (CADRE), which uses dimensional and topological adaptation based on production rules and shape grammars. Liu et al. [14] present a case-based parametric design approach for test turntable, by using a knowledge library composed of parameterized 3D models and a matched case library composed of design specifications. Cheng et al. [15] present a similar parametric approach and applied for hydrostatic rotary table design based on Pro/Engineer. Zhang et al. [16] present a design reuse approach to realize fixture design knowledge retrieval and fixture model retrieval based on ontology. Their approach adopts evolutionary methods to modify the retrieved model to meet the new design requirements. Different from most of the traditional CBD approaches for architectures, Hua [17] presents a new 3D architecture design approach as similar as modeling by examples. However, geometry adaptation is often