Computers in Industry 64 (2013) 869–879

Contents lists available at SciVerse ScienceDirect

Computers in Industry

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

Assembly operation process planning by mapping a virtual assembly simulation to real operation

Q. Yang [a,b,*], D.L. Wu [c,d], H.M. Zhu [c,d], J.S. Bao [c], Z.H. Wei [a]

[a] School of Computer Science and Technology, Nanjing University of Science and Technology, Nanjing, China
[b] School of Computer Engineering, Nanjing Institute of Technology, Nanjing, China
[c] Shanghai Jiao Tong University, Shanghai, China
[d] Shanghai Key Lab on Advanced Manufacturing Environment, Shanghai, China

ARTICLE INFO

Article history:
Received 10 April 2012
Received in revised form 23 March 2013
Accepted 7 June 2013
Available online 3 July 2013

Keywords:
Virtual reality
Virtual assembly
Interactive operation simulation
Process planning

ABSTRACT

Virtual assembly has been widely used in product development. However, virtual operation and actual operation are different in time and space, the simulation of interactive virtual assembly cannot support the assembly operation's process planning directly. In this paper, the solution for assembly operation's process planning is developed based on interactive virtual assembly. According to the solution, interactive assembly operation is used to obtain the actions of operation sequence. The actions are mapped into the data of a real operation action to obtain real operation actions. Then assembly operation cards can be obtained. To support the assembly operation actions obtained through virtual assembly simulation, a product assembly model is proposed. An operation semantic model is used to replace the geometric constraint model of assembly, which contains several ordered geometric constraints and some engineering restriction conditions. To test the solution and the models, one process planning example of an automobile engine is introduced. The results verified the feasibility and the effectiveness of the methods.

1. Introduction

Virtual assembly (VA) has been widely used in product development, such as assembly analysis, assembly sequence path planning, assembly process simulation, and assembly operation training.

There are two main differences between real assembly and virtual assembly simulation: time difference and geometrical difference. Firstly, there is no corresponding relationship between virtual operation time and actual operation time. The simulation time is affected by the response speed of interactive equipment and simulation software. The actual operation time may depend on tools, weights and sizes of parts and operator's gestures. In addition, the operator's action is not free in actual assembly, because his actions may be restricted by parts' gravity and the force caused by constraints and collisions between parts and other objects. In an assembly simulation, operators complete the assembly action through inputting parts' motion parameters without considering the movement restrictions. Some force feedback equipment can provide force feedback, such as the CyberForce. But the equipment cannot restrict the user's movements for the reasons of safety and maximum of feedback force. So we cannot obtain actual body movement elements by assembly simulation.

A complete assembly operation process contains operation time, consequence path, and operator's motion. Because of the differences in time and geometry, users cannot obtain a complete assembly operation process directly from the virtual assembly simulation at present.

In this paper, we present a solution for assembly operation's process planning based on interactive assembly simulation. The interactive assembly operation simulation is used to obtain operation action sequence. A real factor database of operation action is used to obtain the real operation time. The actions are mapped in a real factor database of operation action to obtain real operation actions. To create the assembly operation's actions from virtual assembly simulation, a product assembly model is proposed. An operation semantic model is used to replace the assembly geometric constraint model, which contains several ordered geometric constraints and some engineering restriction conditions.

The above methods are applied in an assembly simulation platform DMSP (Digital Mockup Simulation Platform). A module for creating the assembly semantics in Pro/Engineering system are developed based on PTC proToolkit. An engine's assembly process planning is used to test the methods. The main steps for obtaining an assembly operation process include defining the assembly semantics based on product models in Pro/E environment,

* Corresponding author at: School of Computer Science and Technology, Nanjing University of Science and Technology, Nanjing, China. Tel.: +86 025 86118293.
E-mail address: yqing620@tom.com (Q. Yang).

0166-3615/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.compind.2013.06.001

assembly operation simulation in virtual environment, forming the assembly consequence and paths, and creating assembly operation process.

In the following sections, we firstly discuss the related works and then give the basic workflow for assembly operation process planning based on assembly simulation. The two key points of the solution are respectively discussed in Section 4 and Section 5. A case is given in Section 6.

2. Related work

To improve the performance of CAPP system, researchers introduced virtual assembly into assembly path or sequence planning [1,2], thus leading to the topic of Virtual Assembly Process Planning (VAPP). Compared with extensive study on CAPP, the research of VAPP is still at the exploratory stage [3] and the research topics are mainly focused on assembly path and sequence planning [4,5].

The classic VAPP procedures are provided as follows: some efficient algorithms are applied to generate assembly sequences or feasible assembly path; and then the results are imported into virtual environment to search the best one through virtual assembly or disassembly. The main problem is that the feasible assembly sequence or path reasoning requires too long time, and that operator's randomness during assembly process is not taken into consideration. Yang et al. [6] and Wu et al. [7] adopted constraint-based virtual assembly technology to generate feasible assembly sequence and path through recording the operation process information. But the assembly process model and detailed assembly processes are not mentioned. Liu et al. [8] defined assembly tasks as component assembly operation, and generated the assembly procedure through recording assembly information. But the way to extract the distinguishable operations through the recorded information was not mentioned in their works. The assembly actions from simulation may be unreasonable because of the time and geometrical difference between real assembly operation and operation simulation.

Product assembly model is the basis for assembly simulation. The modeling method has been studied widely. The most representative assembly relationship modeling methods are based on features, constraints and assembly semantics [9,10].

Feature-based assembly modeling method was proposed earlier for assembly code generation, and then was applied widely in many CAPP systems [11]. Then, some researchers have made great efforts to introduce this model into virtual assembly [12]. For it is necessary to extract assembly feature information from CAD models, assembly components should be modeled sternly based on the features in CAD system. The applications indicated that assembly model based on features performed well in supporting CAPP system, but it is too complex to support VAPP system.

Constraint-based product assembly modeling method has been widely used in VA systems, and VADE [11] is the most representative system. In VADE, the assembly tree containing the complete hierarchy of parts and subassemblies and assembly constraints adopted in parametric CAD system was introduced into VA system. The fatal defects of constraint-based assembly modeling method are interpreted as follows: constraints may be recognized or confirmed falsely, and there is no certain meaning of interactive assembly operation. So the constraint-based product assembly model performs less in supporting VAPP.

Product assembly modeling based on semantic is a new method. Liu et al. [13] defined assembly semantic as the abstract description of assembly relationships, implying the constraints among parts, assembly rules, knowledge and actions. Sui et al. [14] brought forward an extended object semantic modeling method and applied it in the distributed virtual assembly. Hui et al. [15] proposed a three-level semantic abstraction (Concept/Function Level, Structure Level and Part/Feature Level) to describe product assembly information. Although the assembly models based on semantics defined above are abundant in engineering information, they are too complicated for good extraction and processing.

3. Assembly operation process planning in a virtual environment

3.1. Basic process for assembly operation process planning based on assembly simulation

In this section, the new method of virtual assembly simulation combined with basic motion actor database is presented to obtain a complete assembly operation process. The process of the method is shown in Fig. 1. And the relevant six steps are provided as follows:

- *The first step*: to obtain product assembly models based on product CAD model.

  A product assembly model should contain parts, components, the hierarchy model, and assembly constraints. The assembly model is often defined in a CAD system, such as Siemens UG NX, PTC Pro/E and Dassault Catia. We can output a data file of the model in the CAD environment.

  Nowadays, geometric constraints are used to describe the position relationship of two or more parts of a product in most CAD environments. The geometric constraints cannot describe an assembly operation directly, so we should define the assembly

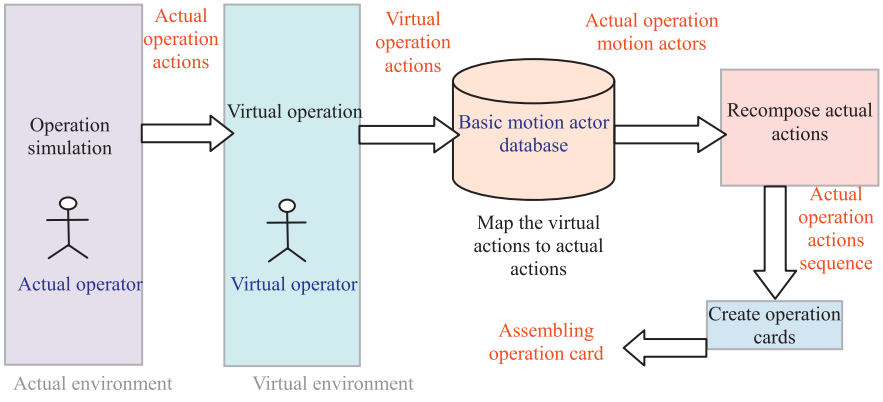

Fig. 1. The process of assembling operation process planning based on interactive operation simulation.