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# Virtual Assembly Method Based on Cad Model Reuse

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**Abstract:** Virtual assembly technology is applied to check the reasonability of product structure and the correctness of product assembly procedure in the virtual reality environment. In order to realize the assembly information acquirement, assembly sequence planning and assembly procedure checking, a virtual assembly method based on CAD model reuse is put forward. The layered assembly tree traveling algorithm is used to obtain the assembly levels, assembly relations and assembly constraints. The assembly matrix analysis method is applied to obtain assembly sequence of component and the final assembly sequence is compounded of assembly sequences of all components top-down. The imaginary projected profile sweeping method is proposed to check interferences among parts and it converts the dynamical assembly checking to the static. The proposed method also provides assembly information for other virtual reality systems. Finally, an application on wind turbine generator system verifies the effectiveness of this method.

**Key words:** Virtual assembly, model reuse, computer aided design, assembly checking, information acquirement

## INTRODUCTION

Virtual assembly takes analysis, transcendent model, visualization and data expression as the means and solves problems on product assembly with software (Qiang, 2010). Designers adopt virtual assembly to find patent defects in the structure and assembly process of product. Virtual assembly not only ensures product quality and reduce production cost, but also provides fresh workers the virtual training environment.

Researches on virtual assembly focus on the construction method of virtual assembly environment (Yang *et al*., 2004), the key technologies of virtual assembly (Zheng *et al*., 2006) and the developing method of virtual assembly system. Virtual assembly environment is the foundation of virtual assembly technologies (Xia *et al*., 2009). Virtual assembly technologies set focus on the friendly operation UI (User Interface). Virtual assembly technologies include assembly modeling, constraints, evaluation and operation effect. These technologies serve the construction of virtual assembly system and some key problems are solved with virtual assembly technologies such as virtual simulation (Christi and Yoon, 2011), assembly modeling, assembly constraints, assembly checking, path planning, patent analysis, chuckle design, process planning, interoperation, assembly control, design modification and artificial intelligence (Yan *et al*., 2004; Zhang *et al*., 2006; Jianhua *et al*., 2004). Above key virtual assembly technologies are applied in applications based on virtual environment, while developing virtual assembly system (Xia *et al*., 2005).

Virtual assembly system is developed generally in three basic methods.

- **Method 1:** The assembly relations, assembly sequence and assembly constraints in product CAD model are imported into general virtual assembly system to realize virtual assembly or other function.
- **Method 2:** The virtual assembly system is built on 3D CAD system. The API of CAD system is used to operate 3D CAD model dynamically and to realize virtual assembly and other function.
- **Method 3:** The virtual assembly system is overall independent to 3D CAD system. Some functions including assembly modeling, assembly information definition and virtual assembly can be executed.

Table 1 is the contrast table of these three kinds of methods.

If the independency is higher, the adaptability is higher and the complexity is lower, the virtual assembly method will be more flexible and suitable to develop

Table 1: Contrast table of three kinds of methods

| Characteristic | Method 1 | Method 2 | Method 3 |
|---|---|---|---|
| Independency | Middle | Low | High |
| Complexity | Low | Low | High |
| Adaptability | Middle | Low | High |

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applications. Though the independency and adaptability of method 3 are higher than other two methods, method 3 is so complex that it is difficult to be realized. Method 1 behaves better independency and adaptability. As mean while the complexity of method 1 is low, so it is usually applied to different kinds of virtual assembly systems.

This paper proposes a novel virtual assembly method based on CAD model reuse. In this method, problems on information acquirement and organization are considered sufficiently and all information includes the assembly structures, assembly levels, assembly sequences, assembly paths, assembly models. Finally some cases based on above-mentioned method are introduced and are used in product design and engineering training.

## FRAME WORK

Design reuse is a new research field. It supports the innovative design of new product by mining, managing and using design resources and makes the usage of design resource higher. Design reuse represents one kind of product design thinking which is advocated by modern manufacturing enterprises (Yu, 2004). This paper takes CAD model as the reuse object and abstract nonstructural information from CAD models. Virtual assembly and relevant applications are realized by reorganizing and reusing all the information abstracted. Figure 1 shows the flow chart of this method.

The proposed virtual assembly method is divided into five basic steps. They are assembly information acquirement, assembly sequence planning, assembly checking and model exporting and reorganizing respectively. Firstly, assembly information concealed in assembly model is abstracted. The assembly information includes assembly levels, assembly relations and assembly constraints. Assembly information is taken as the input of assembly sequence planning. Assembly relations and assembly levels are used to create assembly matrix. Assembly sequence can be acquired by analyzing assembly matrix. An assembly checking method based on the principle of projected extreme profile sweeping is put forward to find out interferences among parts according to assembly sequence and assembly path. Virtual reality model can be exported from Computer Aided Design software according to assembly levels and assembly relations though the data exchange interface. Virtual reality models, assembly paths, assembly sequences, assembly levels and assembly relations will be used to develop applications on virtual reality technologies.

## ASSEMBLY INFORMATION ACQUIREMENT BASED ON TREE TRAVELING

In virtual assembly, solid part models are assembled and controlled top-down according to assembly

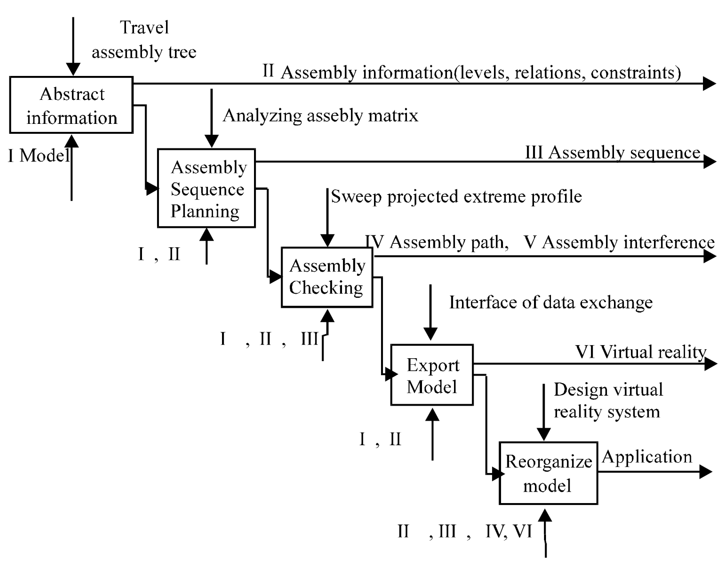



Fig. 1: Flow chart of the method. I: CDA model, II: Assembly information (levels, relations, constraints); III: Assembly sequence; IV: Assembly path; V: Assembly interference and VI: Virtual reality

structures and assembly levels. The complexity of mechanical products makes the efficiency of structure planning lower in virtu ASSEMBLY. For example, 1.5 MW double-fed wind turbine generator system includes 3300 parts almost. This paper presents the assembly tree traveling algorithm by which assembly structures, assembly constraints and solid part models is acquired to serve virtual assembly.

It is hypothesized that the information of No. k part lying in No. j level assembly model is expressed as a quadruple. The quadruple is defined as Pij, k and $^{Pi}$j, k is composed of Ij, k$^F$j, k$^C$j, k and $^P$j, k. $F_{j,k}$ is the total number of the part's father. $C_{j,k}$ is the constraints among parts. $P_{j,k}$ represents the name of part. Assembly constraint $C_{j,k}$ is composed of assembly type and assembly direction. Table 2 shows the directions of different kinds of assembly constraints.

It is hypothesized that assembly model is divided into n levels. There are $m_j$ $(0 \leq j \leq n)$ parts in every level. Figure 2 describes the depth first assembly tree traveling algorithm with the general product assembly structure. The assembly information of node is accessed from assembly tree top-down with the algorithm. Assembly information of every node is expressed as the object of quad-tuple $PI_{j,k} = (I_{j,k}, F_{j,k}, C_{j,k}, P_{j,k})$ $(0 \leq j \leq n, 0 \leq k \leq m_j)$. Give the number i of node in assembly the initial value i = 0 and i = i+1 while next node is traveled. It is hypothesized that the root node of assembly tree is the current node and $F_{j,k}$= 0, $P_{j,k}$= assembly model while j = 0, k = 0. If No. k-1 node is the brother of No. k node in No. j level, then $I_{j,k}$ = I, $F_{j,k} = F_{j,k-1}$, $C_{j,k}$ = assembly constraint, $P_{j,k}$ = part model. If No. i node is the father of the former, then $I_{j,k}$= i, $F_{j,k}$ = i-1, $C_{j,k}$ = assembly constraint, $P_{j,k}$= part model.

Table 2: Directions of different assembly constraints

| Constraint type | Assembly direction | Assembly type | Assembly direction |
|---|---|---|---|
| Mate | Outer normal | Insert | Along insert direction |
| Align | Outer normal | Tangent | Outer normal |
| Coaxis | Along axis | | |

## ASSEMBLY SEQUENCE SYNTHETIC BASED ON LAYERED ASSEMBLY MATRIX

The directed assembly relation graph based on must belong to same component and be in same assembly level. The paper expresses DARGC with constraint (simplified DARGC) is composed of parts according to assembly constraints and all the parts adjacency matrix $A_{j,k}$ and j represents the assembly level and k is the assembly sequence number in No. j level of same component.

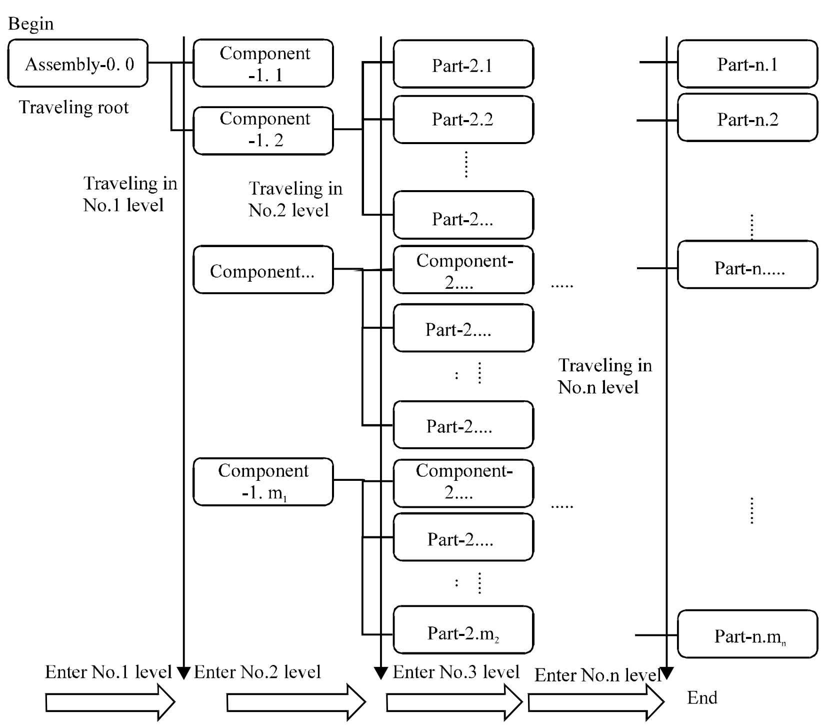



Fig. 2: Depth first assembly tree traveling algorithm

In adjacency matrix, element “1” represents the directed constraint relation corresponding to the column and the row (Fig. 3).

In adjacency matrix $A_{j,k}$, every loop denoted by “1” is a assembly relation for arbitrary part or component and there is always a component or part which will be assembled firstly. Thus there will be one column at least in which all elements are “0” and it is demonstrated that the in-degree corresponding to first-assembled part is “0”. The following width-first traveling algorithm is applied to find assembly sequence among parts or components in same level of same component (Wu *et al.*, 2003).

**Step 1:** Find the column in which all its elements are “0” and the part corresponding to this column will be the beginning of assembly sequence

**Step 2:** Delete the column and the row corresponding to the found part, gain the low-order submatrix of matrix $A_{j,k}$

**Step 3:** Repeat step 1 and 2 to gain the final assembly sequence. The submatrixes will be the object during this process

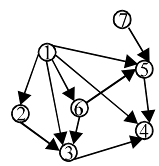
Above mentioned algorithm can be used to gain all levels of assembly sequences top-down in complex product and the final assembly sequence is gained by synthesizing assembly sequences in all levels.

## INTERFERENCE CHECKING BASED ON IMAGINARY PROJECTED PROFILE SWEEPING

Interference checking in virtual assembly is to check the structural interferences between arbitrary two parts in product by means of computational geometry and computational intelligence. Interference checking includes static interference checking and dynamic interference checking. This paper proposed a new interference checking method named imaginary projected extreme profile sweeping. As shown in Fig. 4, parts A and B are assembled into C. The principle of imaginary projected profile sweeping is described as following.

**Step 1:** Firstly, the assembly constraint direction of part model A is taken as the sweeping direction d. The plane P perpendicular to d will be created to act as the datum plane swept.

**Step 2:** Secondly, the outer and inner extreme profiles of part model A are achieved and projected to the datum plane P. These projections comprise the sketch S




$$A_{j,k} = \begin{bmatrix} 0 & 1 & \cdots & 1 \\ 0 & 0 & \cdots & 1 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 0 \end{bmatrix}$$

Fig. 3: DARGC and its adjacency matrix

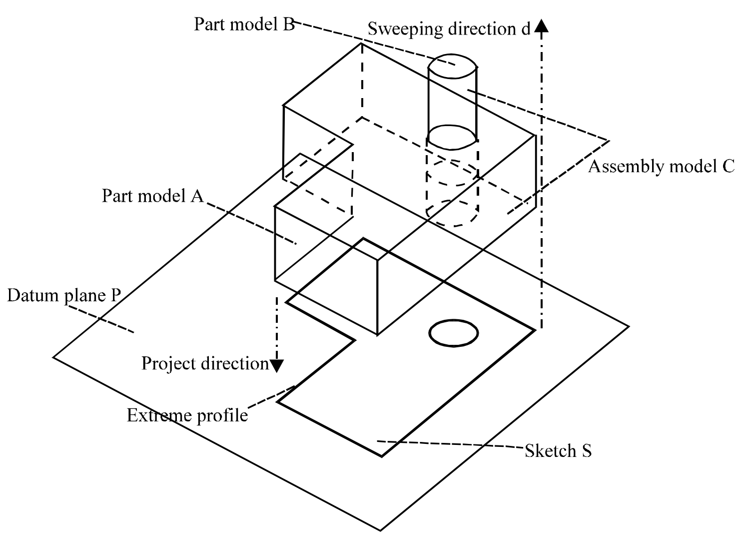



Fig. 4: Principle of imaginary projected extreme profile sweeping

**Step 3:** Thirdly, the sketch S is swept into a solid along the direction d. The static interference checking function of 3D CAD software is called to check the structural interferences between the newly-created solid and the part B and the results will be input into the interference table

**Step 4:** Finally, the newly-created solid, the sketch S and the datum plane P are deleted one by one. It is called the imaginary sweeping, since it is seems that the sweeping never happen during the whole process

The imaginary sweeping method of projected extreme profile is used to check dynamically the interferences among parts according to the inverted sequence of assembly sequence. Interference checking is significant to judge the rationality of assembly procedure. It is considered that the assembly procedure is rational, if there is a constraint direction in which there is no interference between one part and other parts in same assembly level. Otherwise assembly procedure should be irrational. The imaginary sweeping method of projected extreme profile can not only verify the rationality of assembly sequence and assembly structure, but also be used to find the assembly path of part according to the constraint direction without interference.

Interference checking method based on the principle of imaginary projected extreme profile sweeping converts the problem on dynamic assembly checking into the static. The method can reduce the time of interference checking effectively.

## EXAMPLES

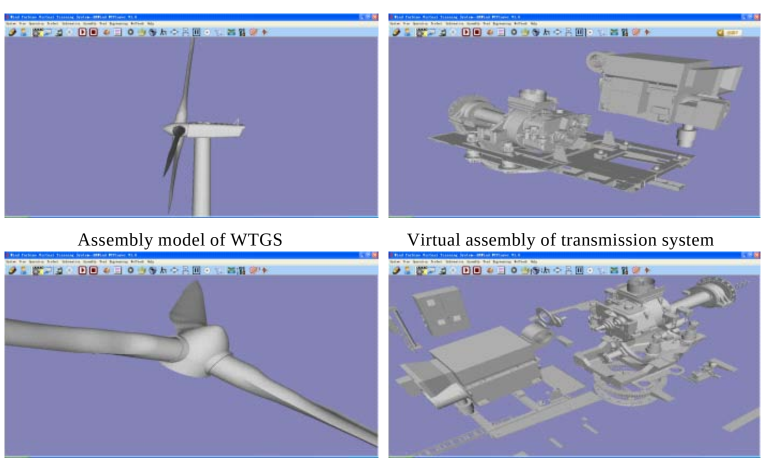
This paper applied the above-mentioned method to realize some virtual reality functions, such as the virtual training of wind turbine generator system, the virtual overhauling of diesel and the virtual assembly of heat exchanger. The general application procedure is as follows.

**Step 1:** Abstract assembly information from assembly model with the proposed method and assembly information includes assembly levels, assembly relations, assembly constraints, assembly paths and assembly sequence

**Step 2:** Export virtual reality files from 3D CAD software through the data exchange interfaces and some formats of virtual reality files are STEP, IGES, DXF, OBJ

**Step 3:** Develop the virtual assembly applications based on 3D CAD software using C++ or other programming language. The applications take the virtual reality files as data and communicate with 3D CAD software through application programming interface. Classical 3D CAD software includes UG, Pro/E and CATIA

Figure 5 shows an application case of the proposed method. It is named the virtual training system of wind turbine generator system, in which the proposed method is used to acquire assembly information of wind turbine generator system and realize the interference checking and simulates the assembly procedure. In Fig. 5



Assembly model of WTGS | Virtual assembly of transmission system

Assembly model of WTGS's wind turbine | Virtual explosion view of transmissions system

Fig. 5: Virtual training system of wind turbine generator system

the left two figures are the virtual assembly model of wind turbine generator and the right two figures are the virtual assembly model of transmission system in wind turbine generator.

The virtual training system of wind turbine generator system has been used by many wind power enterprises. Furthermore, the proposed method is also introduced into other fields such as railway engine, refrigeration equipment. It is confirmed that the proposed method can effectively solve the problem on developing virtual assembly system.

## CONCLUSIONS

This paper put forward one kind of virtual assembly method based on CAD model reuse. This method provides researches some new ways to get the assembly information of complex product and check their assembly procedures including assembly sequences, assembly paths and assembly structure. The method has been confirmed to be feasible and valuable to develop virtual assembly system and other virtual reality applications. Of course, it is also a novel means to reuse CAD models accumulated by enterprises.

## ACKNOWLEDGMENTS

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