A Method of Virtual Assembly Concentric Ball Scanning Path Planning Method Based on Depth Learning

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Abstract. In virtual assembly, it is important to select and determine the best path of assembly. This paper proposes a concentric sphere scanning path planning method based on depth learning, which takes the datum part as the functional center and the radius difference between the two concentric spheres as search step length. Assembly constraints and five-first guideline are constructed mainly with the special sequence and functional sequence. Topological relation tree and relations are used. All the assembling elements are vectorized and digitalized. The spindle assembly is taken as an example for verification. Results show that the method proposed in the current study is of effectiveness.

Introduction

Virtual assembly has a unique role in new product development, product maintenance and operational training with assembly planning or assembly path planning. The assembly path refers to the space path that the components should follow during assembly. From the geometric shapes, the assembly can avoid the mutual interference of the parts, making use of the process activity for the implementation of rationality to ensure the quality of assembly with the productivity. Different reasoning methods have been applied to study the assembly sequence planning and achieved some achievements. Seikguchi [1] based on the assembly of information to establish the assembly diagram, and through the analysis of the assembly diagram and a certain priority relationship to find the assembly sequence of the assembly. Bourjault [2] first according to the information built the assembly diagram, and then through the relationship between the parts of a series of interactive questions and answers access to the priority of the part connection set, which introduced the product of the feasible assembly sequence. Homem de Mello et al. [3] on this basis introduced the assembly cut set analysis method. Based on the correlation graph and adjacency matrix, a subassembly identification and assembly sequence planning method based on mating correlation graph was proposed by Tan Guangyu, et al.[4]. With the gradual maturity of virtual assembly technology, people began to use modern optimization algorithms such as ant colony algorithm, genetic algorithm, particle swarm algorithm, immune algorithm, texture matrix and other artificial intelligence algorithm applied to the assembly sequence planning [5-7]. Liu Yajie et al. [8] used the improved genetic programming method to solve the parallel assembly sequence planning problem. Yao Shouwen et al. [9-11] used assembly liaison graph, adjacency matrix, assembly precedence constraint matrix, sub-assembly identification technology and cut-set algorithm integration, put forward an algorithm of assembly sequence planning.
The Basis of Concentric Ball Scanning Path Planning

The concentric ball scanning path planning is mainly based on the Neural Networks and Depth Learning. Neural network is a machine learning theory, by modeling human brain data processing methods to build the model, the original data as the input layer of the model, the middle through a number of hidden layers of data transformation and processing, and finally the data so treated will be shown as the neuron output. In this process, the known data are vectorization with parameterization, followed by training these data with certain rules and principles. The most important stage is fuzzy reasoning and determining for the solution.

The information of components and assembling units related to the virtual assembly are the known data, and the assembling designation and technical requirement are employed as rules. The wanted assembly path is pursued among the feasible solutions. The structure of the neural network is shown in Fig.1.

![Figure 1. Structure of the neural network.](image)

Definition and Description of Assembly Elements and Systems

Definition of Assembling Elements and Constraints

Elements can be classified into the datum components, ordinary components, and assembling units. The datum components are individual components used as the basic assembly elements onto which other assembling elements fit. Components not used as datum components are ordinary components. Several ordinary components fit onto a datum component may form an assembling unit, such as the set, composite, or assembled part. All these datum components, ordinary components, and assembling units are organically constructed into a machine.

The assembly constraint is that when two completely independent components or parts are assembled in accordance with certain conditions such as position, contact and movement, so that the two components or parts are formed into one unit. These conditions or requirements are thought as assembly constraints.

Digital Representation of Components, Sets, Composites, Assembled Parts, and Total Assembly

Ordinary components installed onto a datum component form the assembling unit, in accordance with the assembly constraints. Components and assembling unit ought to be digitally represented for the assembly path planning. Meanwhile, the corresponding assembly processes should be treated the same way with four assembly levels. The (1, 0) combined vectors of datum components, ordinary components, sets, composites, and assembled parts are denoted by a, b, c, d, e respectively. The (1, 0) combined vectors of assembly processes for the set, composite, assembled part, and total assembly are symbolized by A, B, C, D, respectively, corresponding to the first-, second-, third-, and fourth-level. They are expressed in the form of

\[ a = (1, 0, 0, 0,0...); \quad b = (0, 1, 0, 0,0...); \quad c = (0, 0, 1, 0,0...); \quad d = (0, 0, 1, 0,0...); \quad e=(0, 0, 0, 0,1...). \]
\[ A1 = (a, 1, 0, 0, 0...); \quad A2 = (b, 0, 1, 0, 0...); \quad A3 = (c, 0, 0, 1, 0); \quad A4 = (d, 0, 0, 0, 1); \quad A5 = (e, 0, 0, 0, 1), \] and so on.

All these elements and assembling processes are expressed in vectors and sets.
Virtual Assembly Unit Function Center

In assembly systems, each part must be assembled at least for one time. In order to ensure the assembly accuracy, including and the relative position, the kinematic relation and the fit property, the assembly accuracy should be taken into the assembly constraints. A general approach to achieving assembly constraints is to select assembly criteria and assembly methods in accordance with the assembly drawings. Assembly criteria may be the basis for the centralized definition and description of assembly parts, and may also be a benchmark derived during assembly, and may be involved assembly dimensional chain calculations. From the point of view of assembly engineering, assembly criteria should be preferred for assembly. We define the optimal assembly datum as the functional center of the assembly constraint, represented by vectors

$$E={E_1, E_2, \ldots, E_i, \ldots, E_k}$$  \hspace{1cm} (1)

where, $E_i$, $i=1,2,\ldots,k$, is the functional center of the assembly constraint.

The Principle of Concentric Sphere Scanning Based on Topological Constraint

Basic Assumptions of Virtual Assembly

Virtual assembly principle is through the completion of each assembly part of the space posture and adjustment of the position, constantly moving parts and fitting mats, to achieve the assembly program to achieve the purpose of virtual experiments. The order of assembly should be the opposite of the disassembly one, according to the structural characteristics of parts, the use of appropriate tools or equipment, strictly and carefully in accordance with the order of assembly, people should pay attention to parts and the components accuracy requirements. In order to ensure the normal assembly of the product, the assembly process must strictly be abided by the general principles of automatic assembly.

Topological Relations Tree and Its Composition

Topological relations tree is a system diagram that reflects the relationship between assembly constraints, assembly relationships, quantitative relationships and spatial azimuths in assembly process. As shown in Fig. 2, the basic composition is as follows:

1. Assembly reference system according to the right hand rule, it can be arbitrarily selected, but the coordinates of the origin of the assembly function center is appropriate.(2) There are three cases of assembly constraints: mating relationships; motion relations; relative positional relationships. They are expressed by constraint relation value \{0, 1, 2, 3\}. If it does not belong to the assembly constraint, its value is 0.(3) Assembly benchmark agrees with the assembly principle and assembly requirements, each assembly constraint has a geometric element (point, line or face) and the datum component of the existence of a binding relationship, as the parts of the assembly benchmark.(4) In the product, there are match, movement and relative position relationship of assembly constraints, reflecting the three relationship between the nature and specific technical requirements, constitute the of content transfer accuracy.(5) Sequential path, in accordance with the arrow, arrows function center formed by the chain.(6) The first assembly part is the starting assembly, the last assembly
part is the cut-off assembly, the start and finish of the start-up assembly marks the end of the product assembly.

**Determination of Scanning Step Size**

The radius difference between the adjacent two concentric spheres is the step size, and it is desirable that the minimum dimension of the smallest parts in the scanning direction, which has not been assembled in the system. Taking the unit length as 1.

\[ l_s = r_{i+1} - r_i \]  

(2)

The specific values can be determined by

\[ l_s = \frac{L_s-1}{2}, \quad l_w = \min \{ l_{\text{rest}} \}, \quad i = 1, 2, \ldots, n-k \]  

(3)

where \( k \) is the number of the workpieces ready assembled.

**Virtual Assembly of Concentric Ball Scanning Path Planning Method**

Under the premise of the datum component determined, the radius difference between the adjacent two concentric spheres is the step size, and it is desirable that the minimum dimension of the smallest parts in the scanning direction, which has not been assembled in the system. The ordinary components installed onto the datum component to form the assembling unit for sets, then for composite if the sets added for assembled parts if the composites added, and for total assembly if the assembled parts added. According to the assembly constraints, assembly relations, quantitative relations and spatial orientation, in line with the virtual assembly of the assumptions or agreement to the basic criteria, after layers of assembly, forms a series of different radius, different angles, along the different scanning path concentric circle, as shown in Figure 3.

In coalescence with the search, the virtual assembly guideline, Five Firsts, must be put forward and obeyed: The large components first; the very inside components first; the bottom components first; the heavy components first; the difficult-to-assemble components first. Virtual assembly includes static assembly and dynamic assembly and all elements fit together without collision or interference.

**Applications**

Take the virtual assembly of the CA6140-1 spindle as an example, as shown in Figure 4. The spindle itself as the datum component, the left end of the spindle as the base surface, difference of
the adjacent two concentric spherical radii is the step size. And it is desirable that the minimum dimension of the smallest elements not yet to have been assembled in the system be taken for the search step in the scanning direction. Solution: datum-spindle; path-17,18,19,20,21,22,23,24-16,15,14-11,12,10,9 -8,7,6,5,4,3,2,1.

Conclusions

A concentric sphere scanning path planning method is put forward based on depth learning and with the concepts of assembly constraints for virtual assembly, which takes the datum component as the functional center and the radius difference between the two concentric spheres as step length. Assembly constraints and guideline are constructed mainly with the special sequence and functional sequence, similar to but better than the traditional assembly principles. Topological relation tree and relations are used, all the assembling elements are vectorized and digitalized, and search starts from the datum component and ends at the last ordinary component. The spindle assembly is taken as an example for verification. Results show that the method proposed in the current study is of effectiveness.

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References