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Three-dimensional CAD Model Retrieval Algorithm Based on Ontology

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Abstract

For resolving problems such as how the user implement three-dimensional CAD model retrievals and how to reuse the retrieval results during the smart process planning, this paper present an ontology-based algorithm for three-dimensional CAD model retrieval. The CAD model is segmented into several relevant sub-parts. Then, attach semantic descriptions and annotations to these sub-parts. Finally, evaluate the similarity of the models based on the semantic ontology 3D CAD model. The experimental results show the efficiency of this method to meet the requirements of engineering retrieval and reuse of design and manufacture.

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Keywords: CAD model retrieval; reuse; semantic ontology; MBD

1. Introduction

Because of the continuous development of MBD technologies, 3D model retrieval technique is now widely used in CAD/CAM. Furthermore, it has become an important part of the research of MPEG-73D model standard. The content-based retrieval of 3D model, which can use the features to index and retrieval directly, has broken through the limitations of the traditional retrieval methods employing keywords. However, we note that the study of 3D retrieval is still at the experimental stage and amount of previous work about content-based 3D retrieval has been done by many scholars. In[1], 3D shape retrieval techniques are classified into the following categories based on shape representations: (a) global feature-based; (b) manufacturing feature recognition-based; (c) graph-based; (d) histogram-based; (e)product information-based; and (f)3D object recognition-based. But content-based retrieval, which uses the human perception and understanding of the 3D model to evaluate the similarity between two models, also has its own limitations because the existence of "the semantic gap" between the visual feature and the semantic information. The current retrieval methods prefer to take visual features into consideration rather than the semantic information for the following two main reasons: (1) It is hard for us to express the design intent accurately. Since, design parameters and functions of the model are difficult to be described accurately no matter using the sketch or the model itself as the retrieval access. (2)The lack of semantic knowledge for reusing. The content-based retrieval only returns the related 3D models, making it difficult for the user to get the features' semantic knowledge related to the CAD model from the retrieval result. At present, lots of scholars have begun doing many researches [2.3.4] in semantic retrieval on 3D model, but there are few researches on 3D CAD model. Furthermore, studying in semantic retrieval on 3D CAD model can offer a more targeted approach to reuse the knowledge of the relevant CAD models.

A 3D CAD model can be defined in 4 levels: geometric level, structure level, feature level and semantic level. However, most retrieval methods cannot describe sufficient information of a CAD model on the structure level, feature level and semantic level. They use the single information which got from the shape and would be simplified by some principles to carry out a retrieval. Such as using the histogram organized by the geometric attribute of the CAD model. In this paper, we study the 3D CAD model retrieval on the feature level and the semantic level. Also, the CAD model's information about

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feature, topology, geometric and semantic is employed. The CAD model should be segmented into relevant sub-parts (features or partial structures) that will be described and labeled by the semantic information of the model later. On this basis, taking full use of the model's semantic information and the user's individual information, we implement the semantic-based 3D CAD model retrieval which can express the user's requirement accurately and the result achieves the user's goal well.

2. Segmentation and semantic labeling on the CAD model

2.1. The representation of the CAD model

In general, for evaluating the similarity between 2 models, the feature based methods take into account only the pure geometry of the shape. In contrast, graph based methods attempt to extract a geometric meaning from a 3D shape using a graph showing how shape components are linked together. Graph based methods can be divided into three broad categories according to the type of graph used: (1) model graphs, (2) Reeb graphs, and (3) skeletons. And model graph based similarity methods are applicable to 3D solid models as produced by most CAD systems. The most dominant solid modeling representation methods are boundary representation (B-rep) and constructive solid geometry (CSG).

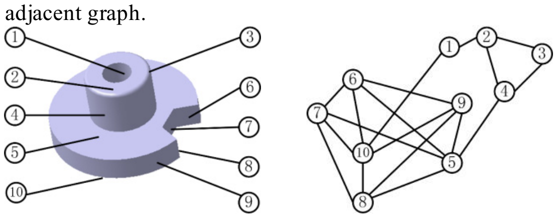
B-Rep is a method for representing shapes using the limits. A CAD model can be represented as a collection of connected surface elements. B-Rep provides explicit representations for the geometrical elements such as vertexes, edges, faces etc., and that is easy to define the relationships between these geometrical elements. By using this method, the geometric information and the topology information of a CAD model can be recorded easily. Moreover, Considering these information recorded by the B-Rep are favorable, in the process of evaluating the similarity between two models, we employ the B-Rep method to represent the CAD models during the experiment. For the reason that the STEP standard has been widely accepted by large-scale CAD software, such as, UG, CATIA, and the data structure of the STEP neutral file is same as B-Rep's, the STEP file is adopted as input during the experiment.

By extracting the B-Rep information of CAD models, the models are represented by attribute adjacent graphs (AAG) in which the nodes refer to the surfaces and the attributes of the nodes represent the geometric properties (type of surface, normal vector, axes, curvature, area etc.), the relationships between nodes correspond to the relationships (adjacent, concavity of the adjacent edges, parallel, vertical, coaxial, coplanar etc.) between the surfaces of the model. The construction of an AAG from a CAD is presented below.

Step 1 Traversal every face of the B-Rep model, and then create a node in the AAG corresponding to the face. The attributes of the node should be set according to the geometric properties extracted from the B-Rep model.

Step 2 Identify the relationship between each two faces which would be set as the relationship between the corresponding nodes in the AAG.

Figure 1 shows a CAD model and its corresponding attribute adjacent graph.



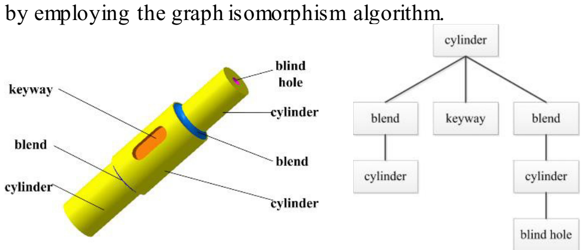
(a) a CAD model (b) the attribute adjacent graph

Fig 1 the CAD model and the corresponding attribute adjacent graph

2.2. CAD Model Segmentation

The current feature extraction algorithm calculating the model can reflect the macroshape of the model, but the partial information is neglected. The CAD model should be segmented into plenty of significant sub-parts (features or partial structures) on the basis of perceptual characteristic by the sake of getting characteristic signals and semantic information of the model to describe the CAD model on feature level and semantic level.

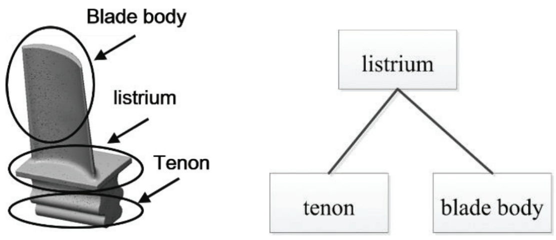
The current research of the models' segmentation which is segmented automatically on the base of scaling functions are mainly on triangular mesh models. As a result, the segmentation can hardly contain engineering semantics information. A shape feature of a CAD model has two properties, the shape and the semantic. These two properties are different from other features according to the specific application. Therefore, this paper segment the CAD model by employing the recognition algorithm in the graph theory after defining the feature (or partial structure) and the feature library according to different application area. Figure 2a shows the subparts of the stepped shaft segmented by applying the feature recognition algorithm. Figure 3a illustrates that the blade model was decomposed into the blade body, the listrium and the tenon by employing the graph isomorphism algorithm.



(a) a stepped shaft (b)feature adjacency graph

Fig 2 the segmentation example of a stepped shaft

The feature adjacent graph can be constructed according to the relationships between sub-parts got from the segmentation. It represents the relationships between sub-parts of the CAD model, in which nodes referring to sub-parts of the model, edges standing for relationships between sub-parts, the properties of nodes and edges corresponding to the attribute information of relationships between sub-parts of the model. Figure 2b and figure 3b are the corresponding feature adjacent graph of the stepped shaft and blade.



(a) a blade (b) the feature adjacency graph

Fig 3 the segmentation example of a blade

2.3. Semantic Annotation

For the purpose of building the bridge between the lower-level feature and the high-level semantic of the 3D CAD model, this paper realized the semantic annotation of the 3D CAD model based on ontology. Ontology is a data set of terminology for describing a particular domain and provides reusing the knowledge and system framework on a high level. We build ontology for storing semantic information of these features and their relationships. In our approach, ontology is represented by a graph, in which a node refers to a kind, and links between the nodes represent relationships of kinds. The ontology can be built as follows: 1) Analyse different applications in the field of CAD and list the typical feature (structure) kinds. Meanwhile, define the hierarchical relations between kinds and form the conceptive ontology tree. The figure 4 shows the kinds of the blade of aviation engine and their hierarchical relations. The model of blade includes five kinds: shroud, damper, body, listrium and tenon. And every class includes a lot of sub-categories. 2) Identify the relations between kinds. The main kinds are: part-of, kind-of, instance-of, attribute-of. Part-of delivers the relation between parts and whole. Kind-of expresses the inheritance relationship between the conceptions. instance-of presents the relation between the conception and the instance. Attribute-of delivers that a certain conception is an attribute of another conception. 3) Extract the attribute of conception and relationships. For instance, the attribute of the "body" can define length, width, angle, accuracy, etc. 4) Create instances of a kind.

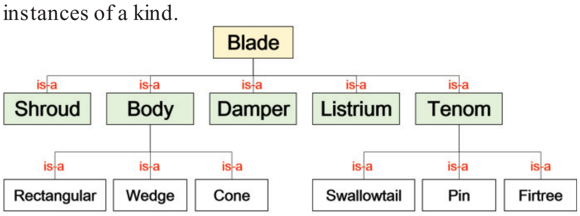


Fig 4 ontology classes and hierarchical relationships of the blade

To label semantic information to CAD models, we should tag the semantic to the global CAD model, such as the name of the model, type, application, process information (material, heat treatment, the type of the blank, etc.). Then, map the sub-parts segmented from the CAD model to the semantic inherited from the ontology of the feature library. Figure 5 shows an OWL representation of a blind hole. Finally, set up the relations between sub-parts to accomplish the labeling semantic to the CAD model.

```
<blindhole rdf:ID="blindhole_1">
<depth rdf:datatype="http://www.w3.org/2001/XMLSchema#float"
>50.0</depth>
<length rdf:datatype="http://www.w3.org/2001/XMLSchema#float"
>10.0</length>
<connect rdf:resource="#cylinder_1"/>
<radius rdf:datatype="http://www.w3.org/2001/XMLSchema#float"
>35.0</radius>
```

Fig 5 OWL representation of a blind hole

3. The Algorithm

The purpose of the CAD model retrieval is to achieve the reusing of the existing model's design and manufacturing information. But the similarity matching only in geometrical shape cannot support the reusing of the relevant information. For example, there are two different CAD models which both have a hole. The types of these two holes are the same but the dimension accuracy and the material are totally different. We can judge that these two CAD models are the same by comparing the shape. But, in the manufacturing, the manufacturing process and the heat treatment of these CAD parts are entirely dissimilar for their dimension accuracy and material. This paper propose the multi-level-based similarity measuring of 3D CAD model, by taking the model's geometry information, topological information, semantic information of the features' function and process information into consideration.

The comparison of the similarity between two models is turned into finding out the largest common subgraph of these two models after the model and its features are represented by AAG. Since defining the largest common subgraph exactly is NP-complete and the algorithm complexity is high, this paper employs hill climbing algorithm to seek a large enough common subgraph. The hill climbing algorithm [5] arbitrarily chooses an initial mapping between the nodes of the two graph firstly. Next, swaps the mapping of the two nodes to make the evaluation function S is minimum and S is the count of the number of mismatched edges. The similarity $S_f = min\ \{S_1,\ldots, S_n\}/|E_1|$ where $S_1,\ldots, S_n$ are the final values of S from up to n and E_1 is the edge set of the smaller graph.

Noted that the manufacturing process is complicated and affected by many factors, we should also consider the similarity of the process information closely related to the manufacturability of products. The similarity of the manufacturability can be decide in the following formula (1).

$$S_p = \omega_m S_m + \omega_h S_h + \omega_r S_r + \omega_c S_c \quad (1)$$

Where S_m denotes the similarity of these two CAD models' material type, S_h is similarity of the heat treatment method, S_r stand for the similarity of the type of the blanks' type and S_c with respect to the similarity of machining demanded precision, ω_m, ω_h, ω_r and ω_c are weighting coefficients [6].

Finally, the multi-level similarity of the 3D CAD models can be measured by weighting aggregate of S_f and S_p.

4. Implementation and Discussion

We verified the algorithm on the basis of path and key technology mentioned above, using Microsoft Visual Studio 2008 as the integrated development environment and Open CASCADE [7] as the development platform and employing the MySQL database to accomplish the operations on the CAD model such as storage, query, renew, etc. The 3D model in the database are mainly acquired from the ESB (Engineering Shape Benchmark)[8] database created by Purdue University. Our dataset contains more than 400 3D CAD model, and the models in the database are expressed by the exchange of product information (STEP) physical file.

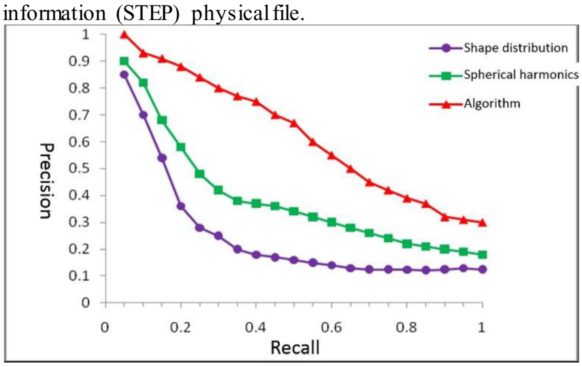
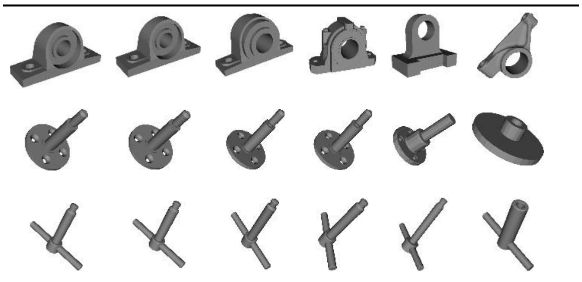


Fig 6 the PR curves corresponding to three algorithms.

Table 1 a part of retrieval results

Input models	Retrieval results sorted by similarity（the top five）				
	①	②	③	④	⑤



We also compare the algorithm proposed in this paper with the shape distribution algorithm [9] and the spherical harmonics algorithm [10] in the experiment. The CAD models in the model database are tested under the experiment to make the comparison of these three algorithms' performance completely. As a result, we receive an average precision-recall(PR) curve. As shown in figure 6, the comprehensive performance using the algorithm mentioned in this paper is significantly higher than that using the shape distribution algorithm or the spherical harmonics algorithm. And, the table 1 demonstrates a part of the retrieval results. Besides, the results of retrieval that represents CAD models by ontology also comprise the features' correlative semantic information of the 3D CAD model in addition to the matching models.

5. Conclusion

This paper presents an ontology-based approach for the retrieval of 3D CAD model. The CAD model should be segmented into several relevant sub-parts that would be described and labeled by the semantic. On this basis, the approach takes full use of the model's semantic information and the user's individual information, then implement the ontology-based 3D CAD model retrieval. Experimental results show that the retrieval performance using this approach is apparently higher than the performance employing shape distribution algorithm and spherical harmonics algorithm.

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