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Research Article

New Technique for 3D Shape Retrieval in the Classified Databases

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Abstract: This study addresses the problem of 3D shape retrieval. While this problem is interesting and emerging as the size of 3D object databases grows rapidly, the main two issues the community has to focus on are: computational efficiency of 3D object retrieval and the quality of retrieval results. In this study we deal with the two considerations, especially the first one namely computational efficiency, by proposing a new technique to retrieve efficiently the 3D-objects in the classified databases which contains 3D objects of different categories. This technique can be coupled with any 3D retrieval method. In this study, we use the Clock Matching Bag-of-Features 3D retrieval method proposed by Lian *et al*. (2010) since it gives the best result comparing with several methods in particular the view based methods. Instead of systematically matching the object-query with all 3D objects of the target database, our approach restricts the pattern matching on a subset of "good candidates" (the most similar to the query). For a database classified in several classes the retrieval will be oriented to the right class that contains similar objects to the query. In this case, the matching process will be not systematically performed with all objects among the database, but only with objects of right class. Our key idea is to represent each class by one representative that will be used to orient the retrieval process to the right class. Experimental results illustrate the efficiency of our approach.

Keywords: 3D classified database, 3D content-based shape retrieval, representatives of classes, right class

INTRODUCTION

Currently, there are an increasing number of 3D models on the web, including large databases, thanks to recent digitizing and modeling technologies. The need of efficient methods for 3D shape-content based retrieval, in order to ease navigation into related large databases and also to structure, organize and manage this new multimedia type of data, has become an active topic in various research communities such as computer vision, computer graphics, mechanical CAD and pattern recognition.

Various 3D shape retrieval methods have been proposed in the literature Lian *et al*. (2010), Remco *et al*. (2010), Tangelder and Veltkamp (2008) and Zaharia and Preteux (2004). All recent methods are based on the indexation of 3D objects; this process consists to designing an efficient canonical characterization of the 3D shape. In the literature, this characterization is referred to as a descriptor or a signature. Since the descriptor serves as a key in the search process, it is a critical kernel with a strong influence on the searching performances (i.e., computational efficiency and relevance of the results). Design an efficient canonical characterization of the objects has become a major challenge in 3D objects indexation.

A good 3D shape retrieval method must satisfy at least two conditions simultaneously (Remco *et al*., 2010):

- **The relevance and the quality of retrieval results:** The first 3D objects returned by the method must be the most similar to the query.
- **Computational efficiency:** The retrieval result should be returned rapidly.

Most existing methods do not satisfy the above conditions simultaneously. Moreover, for the most 3D shape retrieval approaches used in the literature, the matching is systematically performed with all objects in the database (Remco *et al*., 2010). Unfortunately these approaches have several disadvantages:

- **For the large database:** The matching becomes increasingly difficult and needs more computational times; which do not allow the large scale retrieval.
- **For the relevance of the results:** The first retrieval results contain, in general, some objects that are not similar to the query.
- **For the top k answers:** We have to wait until the matching will be completed with all the 3D models

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in the database, even if, only the first top k answers are needed.

In this study, we propose a new technique that overcomes the disadvantages of the actual approaches. Our idea consists in selecting the right objects that could be the best answers (the most similar) to a given 3D-object query. For a database classified in several classes (Biasotti *et al*., 2006; Roberto *et al*., 2009) the retrieval will be oriented to the right class that contains similar objects to the query. In this case, the matching will not be done systematically with all objects within the database. To do this, first of all, we represent each class by a representative (3D-object selected among objects of this class) and then, according to the result of the matching between the query and the representatives, the retrieval will be oriented to the right class.

The retrieval process of our approach is performed as follows:

- First, for each class, we select the best representative.
- Next, for a query object, we select the right class that could contain the best expected answers. This step is performed by using the representatives of classes.
- Finally, the retrieval process will be launched in the selected right class.

DESCRIPTION OF OUR TECHNIQUE

Generally, the 3D-shape retrieval process is performed in two essential and online stages (Remco *et al*., 2010); the first one consists in computing the descriptor of the query object, the second the descriptor of object query is matched with the descriptor of each 3D model in the database. Note that, the query descriptor is computed online while the descriptors of the 3D models in database are computed offline. The similarity between two descriptors is quantified by a dissimilarity measure. For the classical retrieval approach proposed in the literature, retrieval results are returned after the matching process is systematically performed with all objects of the database; unfortunately, these approaches have several disadvantages:

- **For large databases:** The matching becomes increasingly difficult and needs more computational times, which does not permit large scale retrieval.
- **The relevance of the results:** In general, the expected answers are returned with some objects that are not similar to the query.
- Even if for the first top k answers, we have to wait until the matching with all the 3D models in the database is completed.

Our technique is based on the following idea: Why the matching is systematically performed with all objects in the database and why it does not only do with objects that are similar to the query.

Assume that the database is classified into several classes (e.g., Human 3D object is grouped in Human class, Fish 3D object in Fish class). The idea consists in representing each class of the database by one representative (the best one), a 3D object selected among all objects of the target class and then ordering the classes by order of similarity with the query using the similarity between the representatives of classes and the query object. The retrieval process will be primarily performed in the most similar class and if necessary, it will be continued in the other classes, by order of priority. Our approach is performed in the following steps:

- Select representatives of classes
- Ordering the classes by order of similarity according to the distance between representative of each class and the query object. In particular, finding nearest classes
- Launching the 3D retrieval process in classes by order

The remaining of this section is devoted to describe how selecting the representatives and ordering the classes.

Selecting the representative of a class: Assume that the database of 3D-objects is classified into several classes. This section is devoted to describe how to choose the representatives of classes. A representative of a given class is a 3D model selected among all elements of target class. One way is to choose this representative randomly. This way can has strong influences on the relevance retrieval results. In the following, we propose another way that consists in selecting the object that is the most close to all objects of the target class. Assume that the target class is composed of n 3D-objects. The process of selecting the representative is described by algorithm 1. It is performed as follows:

- By using a given 3D shape retrieval method, each 3D-object of the target class, will be matched with the remaining objects of this class.
- For each 3D-object, we quantify its similarity with the (n-1) others. This quantification can be determined, for example, by computing its average distance with the (n-1) other objects.
- The representative is selected as the object that has the minimal average distance.

Algorithm 1:

```
For each 3D object k belonging the target class {
  For each 3D object i belonging the target class {
```

Compare object k with object i
Compute the distance between object k with object i }
Compute the average distance of object k}

Retrieval process according to order of classes: In this section we describe how the classes can be sorted by order of similarity to a given 3D query object. The ordering is based on the distance between the representatives of each class and the query object. The class whose representative has the minimum distance with the query is considered as the class which contain 3D object most similar to the query. The process of the ordering is as follows:

- The query object is compared with representative of each class by using a given 3D shape retrieval method, this method should be the most efficient in term of relevance even if it's not computational efficiency. The result of this step is a set of distances obtained performing this comparison.
- The classes are sorted according to the obtained distances. The class whose representative has the minimum distance is considered as expected class that contains the most similar objects to the query. This class in most nearest class.

After the classes are sorted, the process of the retrieval is performed as follows:

- The retrieval will be started firstly in the most nearest class (the obtained as the expected class) using a given 3D-object retrieval method. When the matching process is completely done with all objects in the class, the results can be returned.
- If the returned results are not satisfied, the retrieval process can be repeat recursively in the remaining classes according to the priority order until the results are satisfied or all classes are explored.

Remarks: Since the proposed retrieval approach is based on selecting representative of each class:

- It is necessary to choose the best object that represents the target class.
- Since the retrieval is primarily oriented to the nearest class by matching the query object with the representatives of the class; it is necessary to choose the more accurate 3D shape retrieval method regardless of its running time.
- In order to increase the chance to fall in the right class, another way is to represent each class by more than one representative.

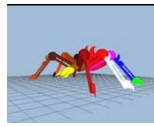
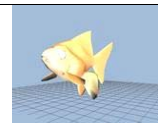
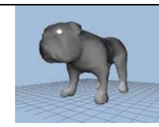
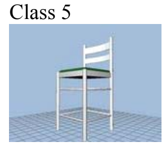
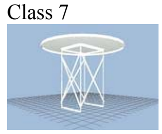
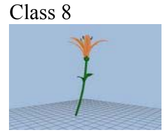
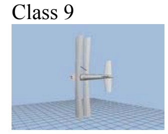
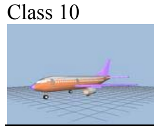
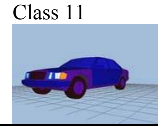
EXPERIMENTAL RESULTS

During all steps of our approach, we have used the CM-BOF 3D retrieval method, proposed by Lian *et al*. (2010), since it gives the best result comparing to several other methods in particular the view based methods Lian *et al*. (2010), Remco *et al*. (2010), Tangelder and Veltkamp (2008) and Zaharia and Preteux (2004). CMBOF is 3D shape retrieval method, which uses Bag-of-Features and an efficient multi-view shape matching scheme. In this approach, a properly normalized object is first described by a set of depth-buffer views captured on the surrounding vertices of a given unit geodesic sphere. Then each view is represented as a word histogram generated by the vector quantization of the view's salient local features. The dissimilarity between two 3D models is measured by the minimum distance of their all (24) possible matching pairs (Lian *et al*., 2010).

Table 1: Number of 3D objects in each class

Classes	Name	Number of objects
Class 1	Spider	11
Class 2	Fish	17
Class 3	Dog	7
Class 4	Human	99
Class 5	Dining chair	21
Class 6	Rectangle table	51
Class 7	Round table	12
Class 8	Flower	15
Class 9	Biplane airplane	27
Class 10	Commercial airplane	19
Class 11	Sedan car	19

Table 2: Representatives that are randomly selected

Class 1	Class 2	Class 3
		
Class 4	Class 5	Class 6
		
Class 7	Class 8	Class 9
		
Class 10	Class 11	
		

We made our tests on the Test Princeton 3D Shape Benchmark database Shilane *et al*. (2004) (907 models categorized within 92 distinct classes). It is not possible to show the obtained results for all 92 classes we showed just the results of 11 classes that present almost categories of Test PSB database. (Spider arthropod (class 1), Dog (class 2), Human biped, Dining chair, Rectangle table, Round table, Flower with stem, Biplane airplane, Commercial airplane, Sedan car). These classes are selected from the Table 1 shows the number of 3D-objects in each class and their names.
The remaining of this section is as follows:

- Selecting one representative for each class (randomly or by using algorithm 1) and then comparing the retrieval performance.
- Comparing the retrieval execution time of our approach with the classical retrieval.
- Selecting more than one representative for each class and then comparing the retrieval performances and execution time.

Selection of representatives: In Table 2 we report the representatives that are chosen randomly whereas in Table 3, we report the representatives that are selected using algorithm 1.

Precision of our retrieval technique: In Table 4 we report the precision (Successful rate) of our retrieval technique for representatives that are randomly selected and for representative selected using algorithm 1. This test shows as the obtained results for representative selected using algorithm 1, are better than those obtained with the randomly selected. For the experimental tests, we have proceeded as follows:

- Each 3D-object of the database is considered as a query
- Each query object is matched with the representatives of each class; in order to determine the right class
- For each class i, we compute the successful rate (the number of queries of class i that are rightly oriented to the class i divided by the total number of objects of the class i)

$$SR(C_i) = Q_i/N_i$$

Q_i : The number of 3D object that are good classed using our technique
N_i : The number of object in class C_i

When the successful rate is different to 100%, for a given class, means that some queries are not oriented to their right class.

The obtained performances are directly depending on the accuracy of the used 3D retrieval method and not because of our technique, the following experimentations show this. On Table 5, we report some queries that are not oriented to their right classes in our previous experimentation. Table 6 shows the retrieval performances (the first top 4) using the classical CMBOF retrieval (the matching is performed with all objects of the database).

Execution time: In this section we compare the execution time between the classical approach CM-BOF (the matching is systematically performed with all objects in the database) and with our proposed technique coupled with CM-BOF. For tests we have selected two queries: the first one the class that contains the maximum of objects (class of human: 99 objects) and the second one from the class that contains the minimum of objects (class of Dogs: 7 objects). We implement all retrieval method in Matlab R2007b, on a personal computer with a 3.30 GHz Intel® Core™ i3-2120 CPU, 4.0GB RAM memory.

The results reported on Table 7 show that our approach significantly improves the execution times compared to the classical approach since, in our

Table 3: Representatives that are selected using algorithm l

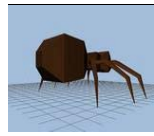
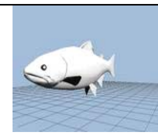
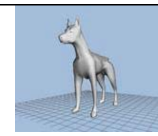
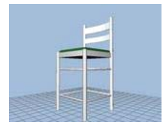
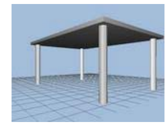
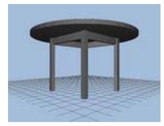
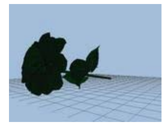
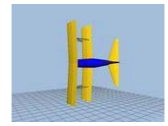
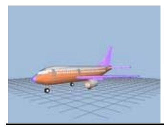
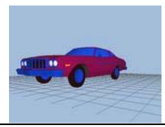
Class 1	Class 2	Class 3
		
Class 4	Class 5	Class 6
		
Class 7	Class 8	Class 9
		
Class 10	Class 11	
		

Table 4: The obtained successful rate for the computed and the randomly representatives

	Successful rate according to the selection technique	
Classes	Random selection	Selection using algorithm 1
Class 1	8/11 (72, 72%)	11/11 (100%)
Class 2	9/17 (52, 94%)	14/17 (82.35%)
Class 3	6/7 (85, 71%)	7/7 (100%)
Class 4	36/99 (36, 36%)	87/99 (87, 87%)
Class 5	21/21 (100%)	21/21 (100%)
Class 6	48/51 (94, 11%)	46/51 (90, 19%)
Class 7	9/12 (75%)	11/12 (91, 66%)
Class 8	5/15 (33, 33%)	6/15 (40%)
Class 9	27/27 (100%)	27/27 (100%)
Class 10	19/19 (100%)	19/19 (100%)
Class 11	19/19 (100%)	19/19 (100%)

Table 5: Queries selected from our database

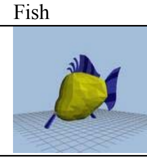
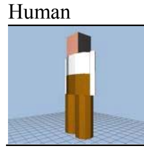
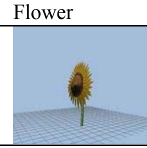
Round table	Fish	Human
		
Human	Flower	
		

Table 6: Retrieval results of the CM-BOF

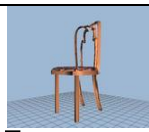
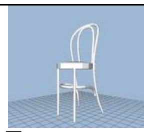
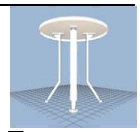
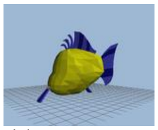
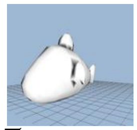
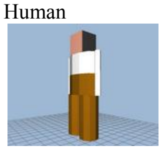
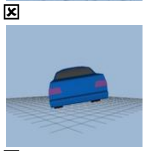
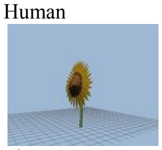
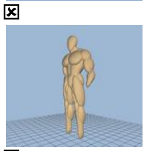
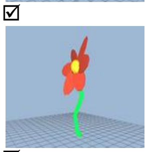
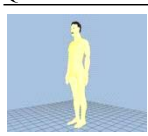
Queries	The order of results of CM-BOF according to the query (from 1 to 3) 1	2	3
 Table round	 ☒	 ☒	 ☒
 Fish	 ☒	 ☒	 ☑
 Human	 ☒	 ☑	 ☑
 Human	 ☒	 ☑	 ☑
 Flower	 ☒	 ☑	 ☒
 Table round	 ☒	 ☒	 ☒

Table 7: Execution times

Queries	CM-BOF	Our technique coupled with CM-BOF
 Human	14, 57 sec	5, 43 sec
 Dog	15, 37 sec	1, 01 sec

approach; the retrieval will be only performed in the obtained right class instead of systematically in the entire database. It is clear that the execution time depends on the number of matched objects. The gain is more important when the class contains fewer objects. In our case the gain is greater than 50%.

CONCLUSION

In this study we have proposed a powerful and computationally efficient technique to speed up the 3D shape retrieval for classified databases. The key idea of our approach is to represent each class by a representative and then, the retrieval will be oriented to the right class (the nearest class to the query object). Experimental results show that the our proposed technique retrieves faster and better, in our case the gain of the execution time is greater than 50% compared to classical approaches where the retrieval is systematically performed in the entire database.

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