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Short Paper:

Extraction and Classification of the Cultural Relic Model Based on Local Geometric Features

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This paper proposes a novel approach to extracting local geometric features of the cultural relic. We first calculate Gaussian and mean curvature of the model. Then the surfaces of model are labeled for three fundamental types by the value of Gaussian and mean curvature. We use the region growing and expanding search method to obtain the local features of the model. We construct the templates based on the local features and prior knowledge. Finally, we achieve the retrieval of cultural relics by comparing the similarity of the template and the local feature of the model. We apply our method to identify and classify on Terracotta Warriors fragments. Experiments show that our method has the good retrieval performance.

Keywords: feature extract, curvature, cultural relic, local feature, surface type distribution

1. Introduction

With the development of 3D visualization technology and the intersection and penetration of related disciplines, Digital archaeology and rehabilitation research have the more convenient means and vast amounts of data [1, 2]. Traditional classification and recognition approaches of cultural relic are based on the professional knowledge of archaeologists. These methods are very time consuming and inefficiency. The repeated exposure of cultural relic can cause secondary damage. Digital Archaeology applies information technology to traditional archeology. It has the advantage of no damage, efficiency and repeatable. Integral geometry in the field of digital archeology has been used for a long time [3, 4]. Fidler [5] adopted the integral invariants as geometric features. He combined it with prior knowledge to achieve the model reconstruction. But he did not give the feature representation for the local geometry of the model. GalR [6] extracted the salient geometric features based on local matching relationship. He took the quadratic fit of local surface to represent the 3D model. Arik [7] applied the partial matching into digital archaeology of cultural relics. Pauly [8] put forward a approach to find the regular geometrical features in the 3D model of buildings. He obtained the same geometric structure by acting on the similar transformation of all the surface points directly.

In this paper, we propose a new method to extract the geometry feature and build a template library of Terracotta Warriors fragments. We adopt Surface Type Distribution (STD) [9] as the retrieval method to classify the Terracotta armor models. The experimental results show that our approach could improve the retrieval accuracy and efficiency of the Terracotta armor models. The rest of this paper is organized as follows. In Section 2, we present our two approaches. Results are demonstrated in Section 3, and conclusions are drawn in Section 4.

2. Our Method

The vertex curvatures of 3D model have the rotation and translation invariance [10]. We use Gaussian curvature and mean curvature to represent 3D model surfaces as three types: concave, convex and flat. As a means of analyzing the local surface, we associate curvature values with each descriptor. In the following, the algorithm to obtain the local geometric features of cultural relic model is described.

2.1. Labeling Surface Types

Taubin [11] proposed the tensor analysis and eigenvector matrix analysis method to compute the curvatures. His algorithm is linear, both in time and in space. All the computations are simple and direct. We use his method to obtain the Gaussian curvature and mean curvature, which represent the concave and convex properties of the surface. Gaussian curvature and mean curvature represent the concave and convex properties of the surface. Besl [12] proposed a threshold function sgn() to compute the curvature sign of every surfaces.

$$sgn_{\varepsilon}(x) = \begin{cases} +1 & x > \varepsilon \\ 0 & |x| \le \varepsilon \\ -1 & x < -\varepsilon \end{cases} \quad \ldots\ldots \quad (1)$$

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Table 1. N value of mean curvature H and Gaussian curvature K.

	K>0	K=0	K<0
H<0	N=1	N=2	N=3
H=0	N=4	N=5	N=6
H>0	N=7	N=8	N=9

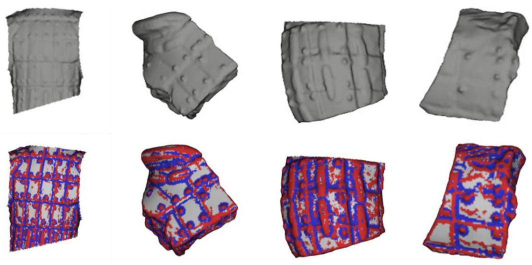

Fig. 1. Different types of vertices of Terracotta Warriors fragments.

x is Gaussian curvature or mean curvature. ε is a zero threshold. Surface types function N is as follows:

$$N = 1 + 3(1 + sgn_{\varepsilon_H}(H)) + (1 - sgn_{\varepsilon_K}(K)). \quad . \quad (2)$$

H and K are mean curvature and Gaussian curvature. In our experiment, we set ε_K =0.0015 and ε_H =0.003. According to N (**Table 1**), we divide the vertices into three types: concave ($1 \leq N \leq 4$), convex ($6 \leq N \leq 9$) and flat ($N = 5$). In order to display the different types of vertices, we use red, blue and white color to respectively represent convex, concave and flat types (**Fig. 1**).

2.2. Regional Surface Growth

Since the vertices of 3D model have been set to three types, the regional surface growth can be made by combining the adjacent and same type vertices. An array Visited [i] is set up to prevent the vertex from being repeatedly access. The queue Q [m] is used to store the different types of vertex. The followings are the procedure:

Step 1: If Q [m] is not empty, go to step 2. If there have the vertices not been visited, select an arbitrary one and search its neighbor vertices, if the neighbor vertex has not been visited and its type is the same as the origin, add it to the end of queue and set it as having been visited, otherwise end.

Step 2: Take a vertex from the front of the queue, and connect it with the origin vertex, then go to step 3;

Step 3: Access to each vertex which is adjacent to search vertex, add vertex which has the same type to the end of search queue, mark it as having been visited, then go to step 1.

After the regional growth was finished, a large number of different sizes of regions have been formed by connecting the same type vertices. These regions corresponding to the types of vertices can also be divided into three types: concave, convex and flat. To extract the local surface features of the model, it is also required to merge the regions based on certain rules.

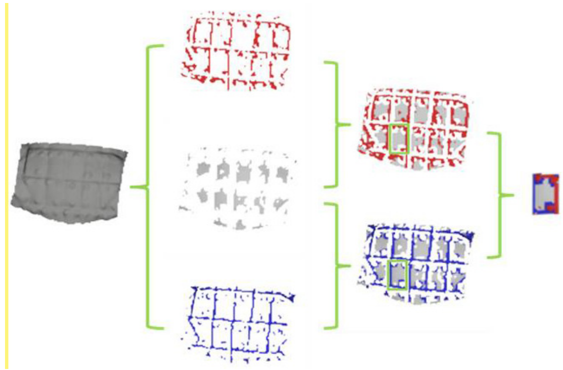

Fig. 2. Extract the local geometric features of Terracotta Warriors fragments.

2.3. Extracting Local Feature

In this section, we put forward an approach to get the local geometric features of Terracotta Warriors fragments. The local geometric feature is a regular feature that characterizes a local partial shape. Each local geometric feature has a number of rotation-and-scale invariant indices which can be used to matching operations and similarity measures. From **Fig. 2** we can see some regular shapes on the surface of the Terracotta Warriors model. Extracting these features can better describe the shape characteristics of these models. The steps are as follows:

Step 1: Select a flat region which has not been visited, query the entire region to find all the boundary vertices;

Step 2: Search the every boundary points, find a region adjacent to search point. If the type of this region is convex or concave, merge it with selected region. When all boundary points have been visited, we set this region as having been visited. Go to step 3;

Step 3: If there still have the flat type regions that have not been visited, go to step 1, otherwise end.

After all flat regions have been visited, we can get one or more salient regions. But some salient regions are very small. Most of them are caused by the model noises. In order to reduce the computational error, we set a threshold n. Let ΔS_i be the relative area of salient region. If $\Delta S_i < n$, we consider that the region is abnormal and merge it with the nearest region. In practice, we take the n =0.005, relative area $\Delta S_i = S_i / \overline{S}$, where S_i is the area of the salient region, $\overline{S}$ is the average area of all salient regions.

2.4. Constructing Template Library

When the local geometric features have been obtained, we can analyze these features based on priori knowledge. The prior knowledge refers to archaeology, historical origin and cultural excavations. We create a certain number the geometric templates of local features based on the prior knowledge and some certain rules. The template library is composed of these templates to achieve the recognition and retrieval of certain cultural relic models. Zhang [13] studied Terracotta armor on shape, structure, size, type, compiling method, production process and decoration in detail. He divided the Terracotta Armor into five types: rectangle, strip, trapezoid, scale shape and abnormality shape. The strip and rectangular armor are more common found in the unearthed Terracotta Warriors fragments, which provides an important foundation for us to build Terracotta armor library templates. We propose a method to build a library template of Terracotta Warriors Armor based on [13, 14].

Step 1: Select the relatively complete local geometric feature to add into the template library;

Step 2: If the new feature can be obtained by the geometric transformation from the templates which was already in the library, delete it;

Step 3: According to the actual retrieval results, remove the template which has few matched numbers from the library.

We apply the method to Terracotta warriors armors, established a template library which has about 30 armor templates. When given a model, we extract the local features and query the template library for each local geometric feature to determine it whether is Terracotta armor. The template library can improve efficiency of the classification and restoration. This method can also be applied to other cultural relic models by appropriate modification.

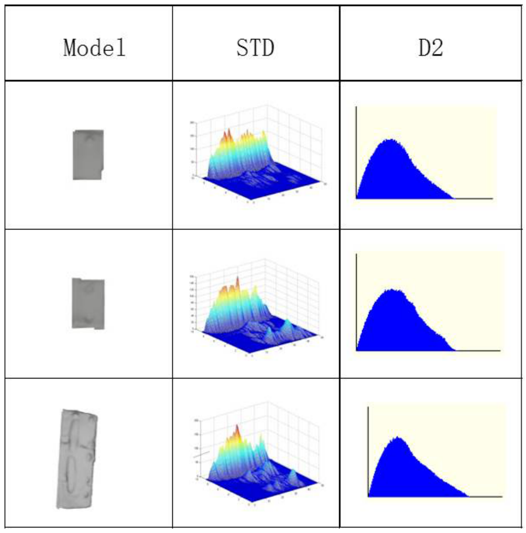

Fig. 3. Example of D2 and STD.

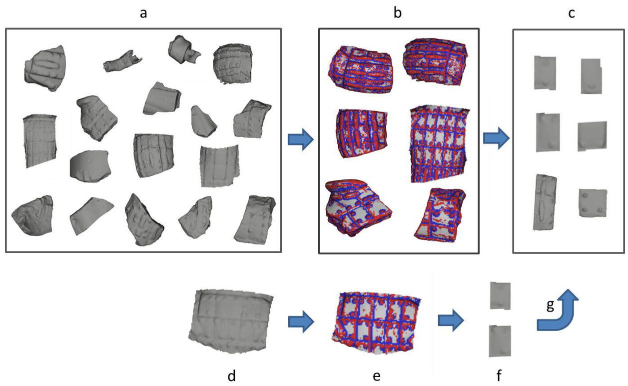

Fig. 4. Overview of similarity retrieval.

2.5. Partial Shape Retrieval

Once the local features were obtained, we need to retrieve them in the template library. This requires a suitable retrieval algorithm. We propose a retrieval method Surface Type Distribution (STD) [9]. The main reason why we choose this method is that it use mean curvature and Gaussian curvature as a part of feature descriptors. This can significantly reduce the time of feature extraction. The details are as follows: First, we select 10000 random points on 3D model and compute Gaussian curvature and mean curvature of these points. The surface surrounding each sample point is labeled for one of eight fundamental types by the threshold function sgn(). Second, we set 3D model's centroid as the center of the ball shell radius and calculate the Euclidean distance between each sample point and the model's centroid. The Euclidean distance and surface types denote respectively as two coordinate axis. A surface type distribution matrix is constructed by obtaining the statistic data of the sample point at different radius of spherical shell and their labels in each surface. Finally, the similarity comparison of surface types distribution matrix is given between different models. According to surface types of random points and number of random points falling between each spherical shell, we construct an 8×50 matrix. Each column of matrix means the distribution of surface types in a certain distance from the centroid point. Each row of matrix means the distance distribution of the same surface types.

Figure 3 shows the D2 histogram and STD matrix of three models. We can see that all models have the similar D2 histograms. This is because D2 histograms only extract the spatial coordinate information of 3D model. It is not able to effectively represent the geometrical information of 3D model surface. STD matrix contains curvature features of 3D model surface. These features can effectively reflect the complex shapes of 3D model.

3. Experiments

In this section, we apply some experiments to test the performance of our method. The experiments are performed on Intel(R) i5-2400 3.10 GHz CPU with 4 GB of memory. **Fig. 4** is our framework for shape retrieval. Given a database of Terracotta Warriors fragments (a), we extract local geometric features (b). Then we construct a template library (c) based on the prior knowledge and certain rules. When given a query model (d), we analyze it in the same method, defining local surface descriptors (e) and salient geometric features (f). For each local geometric feature, we query the template library to determine the model whether it is Terracotta armor (g).

We select 300 Terracotta Warriors fragments (including

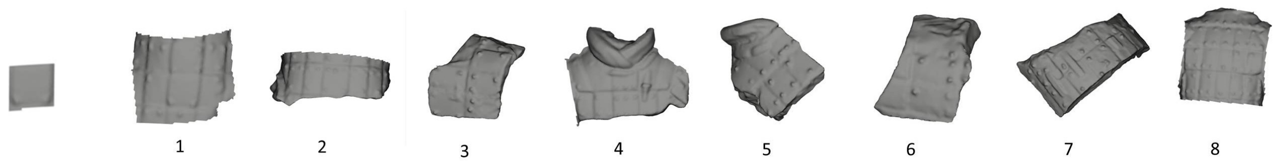

Fig. 5. Similarity retrieval results for a query with an armor template. The figure shows the eight best matches.

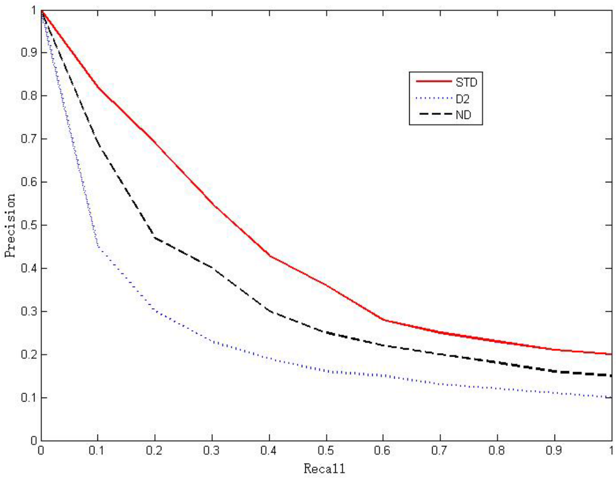

Fig. 6. Precision–Recall curve.

Table 2. The extract and retrieval time of three methods.

Descriptors	Extract time (msec.)	Retrieval time (msec.)
D2	63	22
ND	162	63
STD	129	45

153 armor pieces and 147 other pieces). After extracting the local geometrical features, we match the local features by using STD method to retrieve the query model in the Terracotta armor template library. We use the Manhattan distance to measure the difference between the models. M_A and M_B are the surface type distribution matrix of model A and model B. SIM() is the similarity between two models. If the similarity is less than a given threshold is considered similar. In practice, this threshold is set to 0.15.

$$SIM(M_A, M_B) = \sum_{i=0}^{n} \sum_{j=0}^{m} |a_{ij} - b_{ij}| \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Figure 5 shows the eight best matches. We can find that the retrieved models are not necessarily globally similar (e.g., some Terracotta Warriors fragments are irregular and some short and wide), but they have enough partial similarities.

We used the Precision–Recall curve to evaluate the performance of our method with D2 [15] and ND [16]. D2 represent the signature of an object as a shape distribution sampled from a shape function measuring global geometric properties of an object. It measures the distance between two random points on the surface. ND adopts the angles between the normal of the points and the line segment which is formed by the two random points to calculate shape distribution histograms associated with the D2 shape distribution function. According to **Fig. 6**, STD performs much better than the other two methods. This is because that STD is the combination feature of the curvature information and distance information of random points on the surface, it extracts more geometry features from complex surface than D2 and ND.

The computation time required for feature extraction and 3D model retrieval is shown in **Table 2**. Since curvature calculation has been done in the process of local feature extraction, STD takes less computation time than ND in the feature extraction process. The computation time required for 3D model retrieval is smaller than that required for feature extraction.

4. Conclusions

In this paper, we propose a new method to extract and classify the local features of Terracotta Warriors fragments. First, the vertices of the model are divided into three types: concave, convex and flat by calculating Gaussian curvature and mean curvature. Second, we obtain the local features of the model based on the regional surface growth and certain rules. According to the local geometric features of the model, the template library is established. Finally, we archive the recognition of the model fragments by comparing the similarity of the local geometric features between the template and the testing model. Our method is useful for the type of cultural relic models which have certain regularity and repeating ornamentation (**Fig. 7(a)**). We have presented an application on classifying Terracotta Warriors fragments. However, other types need be further investigated to extract suitable local geometric features (**Fig. 7(b)**). In the next, our research work is to find a more effective method to extract and compare the local geometric features of the cultural relic models.

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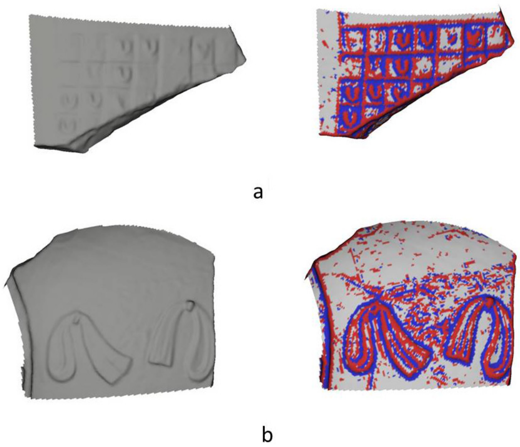

Fig. 7. Different types of cultural relic models.

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