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Robust surface segmentation and edge feature lines extraction from fractured fragments of relics

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Abstract

Surface segmentation and edge feature lines extraction from fractured fragments of relics are essential steps for computer assisted restoration of fragmented relics. As these fragments were heavily eroded, it is a challenging work to segment surface and extract edge feature lines. This paper presents a novel method to segment surface and extract edge feature lines from triangular meshes of irregular fractured fragments. Firstly, a rough surface segmentation is accomplished by using a clustering algorithm based on the vertex normal vector. Secondly, in order to differentiate between original and fracture faces, a novel integral invariant is introduced to compute the surface roughness. Thirdly, an accurate surface segmentation is implemented by merging faces based on face normal vector and roughness. Finally, edge feature lines are extracted based on the surface segmentation. Some experiments are made and analyzed, and the results show that our method can achieve surface segmentation and edge extraction effectively.

Keywords: Surface segmentation; Edge lines extraction; Fractured fragments; Relics

1. Introduction

Cultural relics are the products of social activities for human beings in certain historical periods, and they have historical, scientific and artistic values. However, due to the nature and human activities, many archeological finds are damaged and cultural relics are broken into a pile of fragments when they were excavated. So, surface segmentation and edge detection from fractured fragments are important for cultural relic protection. In recent years, the development of 3D scanning and image processing technology allow us to digitize the fragments of relics accurately. In the 3D virtual cultural relic restoration, the first steps are surface segmentation and edge detection, and then the face and edge characters are used for fractured fragments recombination.

In this paper, we focus on surface segmentation and edge feature lines extraction on triangular meshes from fractured fragments of relics. Unlike the common models, color and texture of fractured artifacts fragments were missing long ago, so surface segmentation and edge extraction have to be only based on the geometry feature. In addition, there are several challenges for surface segmentation and edge extraction on fractured fragments of relics. Firstly, the shapes of fragments are complicated, and the number of faces for each fragment is unpredictable. The size and shape of the fractured surface usually affect the result. Secondly, the fragments may be abraded heavily by the nature in a long time, which makes the obvious feature disappear on the boundary of fragments. Because of abrasion, the normal vectors of the vertex in some area may tend to be similar, which affects the accuracy of surface segmentation. Thirdly, the surfaces of fragments are often rough with much noise, which will make it difficult to distinguish between original and fractured surfaces.

1.1. Related work

1.1.1. Surface segmentation

Efficient segmentation of globally optimal surface is well-studied in many applications, including medical image analysis, 3D model modification, and feature detection. Mangan et al. [1]

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segment the surface into patches by using the total curvature of the surface as an indication of region boundaries. Eugene et al. [2] borrow the ideas from Morse theory to segment surface based on an automatic parameterization method. Zhao et.al [3] first use the morphological residues to detect edges, and then apply a triangulation method and a region-growing scheme based on critical points and surface normals for segmentation processing. Georgios et al. [4] use crest lines for surfaces segmentation. They calculate the largest curvature and its corresponding domain direction on each vertex to classify crest points. Then, they segment flatten the surface by calculating crest lines on Geodesic Voronoi diagram. Gabriel et al. [5] introduce the geodesic centroidal tessellation to compute a segmentation of the manifold, and derive a fast algorithm based on a geodesic gradient descent to deal with special features of the mesh. Sun et al. [6] first detect the edge by using eigen analysis of the surface normal vector and compute the strength for each vertex. And then, they use the watershed algorithm to segment the surface based on the edge information. Kang et al. [7] transform the surface segmentation problem into computing a minimum s–t cut in a weighted direct graph, and use the graph theory to accomplish surface segmentation in volumetric images.

1.1.2. Edge extraction

Feature line extraction is a key issue in many scientific fields, such as computer graphics, medical imaging, computer vision and computational fluid dynamics. Some research efforts extract feature lines on point clouds data in the past. Huang et al. [8] introduce the integral invariants to extract the edge feature points from fractured objects by computing multi-scale surface characteristics. Gumhold et al. [9] first use Riemannian tree to create the topology structure, and then use covariance analysis to classify feature points, finally compute a minimum spanning tree of feature points. In order to deal with noise robustly, Pauly et al. [10] use multi-scale analysis by changing the size of the local neighbors. Demarsin et al. [11] focus on extracting closed sharp feature lines. They use first order segmentation to indentify feature regions, and then construct a minimum spanning tree for closed feature lines. Weber et al. [12] present a method for detecting sharp features based on a Gauss map clustering on local neighborhoods without any user interaction.

More researches on feature extraction are based on triangular meshes. Christian et al. [13] obtain the feature points through computing vertex curvature value on triangle meshes. Then they remove noise and artifacts with a morphological operator and maintain the skeleton of the feature region. Ohtake et al. [14] propose a method by constructing multi-level implicit surface for detecting ridge-valley lines on dense triangle meshes. Klaus et al. [15] introduce a scheme based on discrete differential geometry, and then they augment this scheme by a filtering method to improve the stability and smoothness for feature lines extraction. Yoshizawa et al. [16] present a method that estimate the curvature tensor and curvature derivatives via local polynomial fitting to detect the crest line on meshes. Yoshizawa et al. [17] extend the local polynomial fitting scheme [16] and the general finite-difference curvature tensor fitting approach [18]. They exploit intrinsic geometric properties of the curvature extreme and provide with an inherent level-of-detail control of the detected crest lines. Weinkauf et al. [19] present a method based on topological analysis of principal curvatures, which does not depend on curvature derivatives as previous extraction schemes. They then introduce the concept of separatrix persistence to smooth edges and keep the most salient parts only. Vidal et al. [20] propose an automatic method for robust detection of crest lines by introducing an estimator for angle among tangent plane normal vectors on triangular meshes, in particular CAD models. This method outperforms classical techniques in the presence of noise.

Our method combines and extends existing techniques from different research fields to segment surface and extract feature lines of relics on triangular meshes.

1.2. Method overview

In this paper, we propose a novel method for segmenting surface and extracting edge feature lines on triangular meshes from fractured fragments of relics which may be eroded heavily and have large noises. Given a fragment presented by triangular meshes, our method first applies the Laplace operator to smooth the surface and remove noise. We get a rough surface segmentation by using a clustering algorithm based on the vertex normal vector. After that, we remove the noise faces with few points produced in clustering. Then, we introduce the integral invariant to describe surface roughness and differentiate between original and fractured faces. In order to get better affect of edge extraction and optimal surface segmentation, we merge adjacent faces based on face normal and roughness. Finally, we extract the edge feature lines from fragments of relics.

Most of the existing surface segmentation and edge extraction methods are designed for complete models, and they are not suitable for fractured fragments. Fractured fragments of relics are different from common models, their surfaces are rough and contain large noise, and their sharp features disappear because of abrasion in a long time. Our method is designed according to the characteristics of fragment models. Comparing with existing methods, our method has following advantages: a) our method can differentiate between original and fractured faces, which is important to relics restoration; b) our method is able to deal with cylndrical surface, which has large bending energy; c) our method is focus on the fragments which are heavily eroded; d) our method is robust for the fragments with large noise; e) our algorithm has the linear time complexity.

The rest of this paper is organized as follows. In Section 2, we use the Laplace operator to smooth the surface and remove noise. In Section 3, we present a clustering algorithm based on vertex normal vector to complete a rough surface segmentation. In Section 4, we introduce the integral invariant to differentiate between original and fracture faces. In Section 5, we extract the edge feature lines after merging adjacent faces