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Axis estimation and grouping of rotationally symmetric object segments

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A B S T R A C T

This paper proposes a new method for estimating the symmetric axis of a pottery from its small fragment using surface geometry. Also, it provides a scheme for grouping such fragments into shape categories using distribution of surface curvature. For automatic assembly of pot from broken sherds, axis estimation is an important task and when a fragment is small, it is difficult to estimate axis orientation since it looks like a patch of a sphere and conventional methods mostly fail. But the proposed method provides fast and robust axis estimation by using multiple constraints. The computational cost is also too lowered. To estimate the symmetric axis, the proposed algorithm uses three constraints: (1) The curvature is constant on a circumference C_H. (2) The curvature is invariant in any scale. (3) Also the principal curvatures does not vary on C_H. C_H is a planar circle which is one of all the possible circumferences of a pottery or sherd. A hypothesis test for axis is performed using maximum likelihood. The variance of curvature, multi-scale curvature and principal curvatures is computed in the likelihood function. We also show that the principal curvatures can be used for grouping of sherds. The grouping of sherds will reduce the computation significantly by omitting impossible configurations in broken pottery assembly process.

1. Introduction

Cultural heritage protection digitization has become a new research direction in cross-disciplinary of information technology and archaeology. Too much emphasis cannot be put on preserving and reconstruction of artifacts found on excavation sites. Especially, a number of pottery are excavated usually in their fragments called sherd and should be re-assembled to be restored. The most common assembling practice is through professional experience by human operators to estimate the configuration of the broken fragments. Virtual assembly methods of sherd using computer vision techniques are developed to help such time consuming tasks [5,18,11,12,15,3].

Sets of point cloud are acquired using laser scanner [1]. Estimating 3D shape from dense-data laser scans or from multiple images, each taken from a different position is a fundamental problem of wide applicability in 3D computer vision. Whereas fairly general shapes are of greatest interest, quadric patches are of widespread use and generalized cylinders, which are the shapes of our pot sherds, are of less, but still considerable applicability. Planes, spheres, cylinders, and generalized cylinders constitute models for the parts of much of what we see and model in 3D scenes. For archaeology applications, analysis of pot sherds is a major source of information, to archaeologists, for understanding the civilization at the site. At present, the information of major importance to the archaeologists is the geometry of the pot neck and the pot bottom, but if many of the body sherds could be re-assembled quickly into pots, then heretofore not available information, e.g., pot volumes and shapes, would be available and of major use. The pot re-assembly problem can be viewed as 3D puzzle solving. More generally, the problem can be viewed as making inferences about objects based on somewhat unreliable small pieces of information and subject to local and semi-global geometric constraints. This is a central problem in computer vision and pattern recognition. The more accurate the small pieces of information, the better is the chance of successfully estimating or recognizing the object. The focus of our paper is on maximizing the accuracies of these small pieces of information.

For the axis estimation of rotationally symmetric objects, a Hough-based approach to the problem is presented [21]. The Hough transform is a robust method since it is based on a voting principle. For an object of revolution (such as an archaeological pottery made on a rotation plate), all intersections of the surface normals N_i are positioned along the axis of symmetry. They clustered intersecting normals and determined the axis.

Yokoya and Levine [22] use the center of the principal curvature from first and second partial derivatives of the surface, which

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construct the so-called focal surface and they also use Hough transform to find the axis. However, when a fragment is small, Hough transform methods do not have sufficient voting for the axis orientation.

Profile curves are used to investigate geometric properties of pottery or sherds. Profile curves turn out to have important structural information and can be used for determining if a pottery is manufactured on a wheel or estimating the rotational symmetric axis [5,14,19]. Cooper improves the speed of method by employing sub-sampling and bootstrapping methods [17]. Especially in [19], circle fitting method is employed for both profile curve estimation and axis estimation. This is comparable work to ours and carefully compared using linear and non-linear methods.

A few methods for automatic assembly of pot fragments have been developed. Kampel [10] introduced a method for reconstruction of broken sherd by calculating the axis of rotation using the fact that surface normals of rotationally symmetric objects intersect their axis of rotation and then using both inner and outer surfaces, a profile curve is generated. Finally, they perform a break surface matching procedure using a modified ICP (iterative closest point) algorithm.

Cooper et al. [4,5] developed a method for fragment matching based on a Bayesian approach using break-curves, estimated axis and profile curves. It is a bottom-up maximum likelihood performance-based search and is associated with sub assemblies of fragments via a likelihood of energy functions.

All of the above methods for axis estimation need sufficiently large sherd which has abundant shape information for the estimation. Unfortunately, sherd excavated on the sites come in various sizes and conditions (Fig. 1). The sherds could be small and their surfaces and break-curves could have been weathered and eroded. Hence a robust method is required which can deal with such difficulties.

We proposed in an earlier work a method which estimates the axis by using the curvature of a planar curve which is the intersection of a surface data and a hypothetical plane [13,8] and here further developed and experimented. The variance of curvatures and multi-scale curvatures are computed on the curve since all the points on a circle must have a same curvature k. The principal curvature is also used. Generally, the principal curvature does not coincide with the curvature of a circumference of an rotationally axis symmetric object since the curvature of a circumference depends on the axis orientation. However, the principal curvature must be consistent on the circumference. Furthermore, when the axis cannot be uniquely determined due to the small size of a sherd, the proposed method can provide the probability space of axis configuration which can be used in Bayesian framework of assembly.

Another contribution of this paper is grouping of sherds. While the principal curvatures are computed in the likelihood for axis estimation, the distribution of them can be also used for grouping sherds. It is an important issue to reduce the number of computation since assembly of pottery must have a combinatorial search in any method. For the computation of likelihood or comparing break curve, combinatorial search is a required step for assembly. By grouping, the original assembly problem is divided into the smaller set of problem and the number of the total computation will reduce.

The rest of this paper is organized as follows: In Section 2, axis estimation problem using curvature invariance is introduced. In Section 3, the proposed methods are described in detail and accuracy of axis estimation related to the size of sherd or shape is analyzed. In Section 4, grouping of sherd via principal curvature histogram is discussed. The experiment results are presented in Section 5. Finally, the conclusion and future work will be discussed in Section 6.

2. Rotational symmetric axis

For assembling sherd, the rotationally symmetric axis information plays very important role as well as the break-curves (curves on a pot surface separating fragments) since it removes unnecessary configuration of sherd in curves matching process. However, it is not a trivial task to find the rotational axis from a broken piece of an axially symmetric object since the broken part may not supply enough information. Depending on the shape or size of the surface, the axis can be found or not. For example, if a pottery is spherical shape, the axis cannot be determined and if a sherd is small, it is often the case that it looks like a patch of a sphere. In practice, the sherd excavated is in many different sizes and shapes. All of the previously developed methods in Section 1 were

Fig. 1. A complete pottery made in the 13th century in Asia but many of them are found in pieces.