Estimation of Profiles of Sherds of Archaeological Pottery

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Abstract

In this paper, a method for a profile estimation of an archaeological pottery based on their fragments (sherds) is presented. Since investigated pots were made on a potter's wheel, the rotational symmetry of the original objects is assumed. In addition, sherds are oriented before the estimation. Using these constraints, an acquisition method based on a model of a sherd is proposed. The method is simple, stable and robust. The proposed method has been tested on both synthetic models and real archaeological sherds.

1 Introduction and Motivation

In the field of archaeology one of the most important objects are sherds (fragments of pots). When a new sherd is found, it needs to be measured, classified and archived. Until now archaeologists have classified sherds manually, which represents a great deal of routine work and takes much time (from 1/2 to 3 hours for each sherd). To cope with this fact, several projects of a computer aided classification of sherds have been introduced in [3], [7] and [6]. In the last project, an automated acquisition of a shape of the sherd is also proposed, see [5]. The method is based on stereo and structured light approaches and produces a 2.5-D model of the sherd (so called range image or depth map). In this paper we focus on a further processing of such data. In particular, we propose a method for automated estimation of a profile of a sherd.

The profile of a sherd is defined as the intersection of the sherd with the plane going through the rotation axis of the pot to which the sherd belongs. Rotational symmetry of original pots is assumed in this definition. However, regarding the fact that pots were made on a potter's wheel, this assumption is fulfilled. The profile is one of the most important characteristic of a sherd. Based on their profiles, sherds are divided into different prototype categories during the classification. In addition, when an original pot is reconstructed from its fragments, the profile of a sherd is used for an orientation of the sherd and for its placing to the proper position on the reconstructed pot. Thus for a successful reconstruction the profiles of the pot's fragments need to be estimated with high accuracy. Robustness and accuracy of the profile acquisition is also required in an automated pot reconstruction proposed in [1].

In this paper, a simple and robust method for an estimation of a sherd's profile is proposed. The method exploits the constraint on rotational symmetry of the original pots. Expert knowledge is also used to simplify the whole task. The paper is organized as follows: in the next Section, the estimation method is described. Experimental results are discussed in Section 3. Section 4 concludes the whole work.

2 Profile Estimation

An interesting method for an estimation of a diameter of an archaeological pottery from its sherds has been proposed in [2]. In that method the sherd is manually oriented in the measurement area and illuminated by a laser plane. The intersection of the plane with the surface of the sherd is observed by a camera. By knowing the orientation parameters of the sherd, camera and laser, the diameter is acquired directly from the image of the illuminated sherd. Now we extend that approach to a simple and robust profile estimator.

The estimation process is based on the following fact illustrated in Figure 1(a): If O is a rotationally symmetric object with the axis of rotation a and p is the plane perpendicular to this axis, the plane intersects the object in a circle c. Now assume that only a fragment F of the object O is available as depicted in Figure 1(b). After a proper orientation, the intersection of the same plane with the fragment will form a part of the original circle c denoted as c'. In both cases the radius r of the circle c corresponds to the perimeter of the object in the given position.

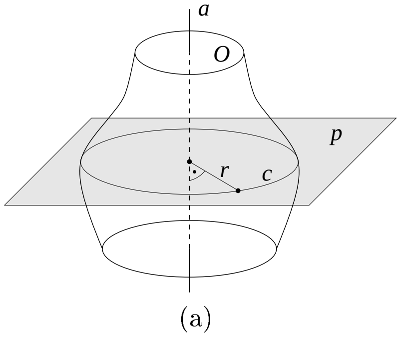


Figure 1: A model of a rotationally symmetric object (a) and its fragment (b)

Regarding rotational symmetry of original pots, the appropriate perimeters can also be estimated from sherds of archaeological pottery. Assuming that, the profile of an investigated sherd can be acquired as depicted in Figure 2. First, a sherd S is intersected by planes perpendicular to its rotation axis a at different positions p_i. Next, the corresponding circles c_i are estimated. Finally, the acquired perimeters r_i are combined together and the profile P of the sherd is constructed.

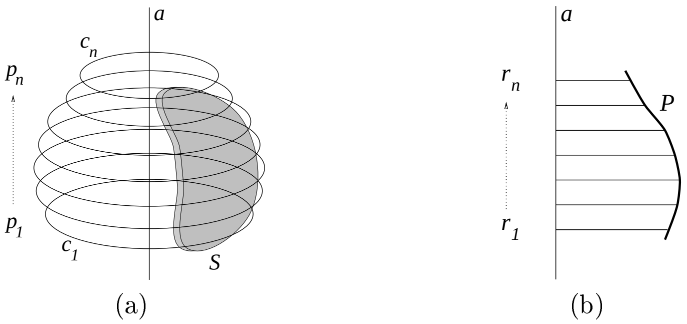
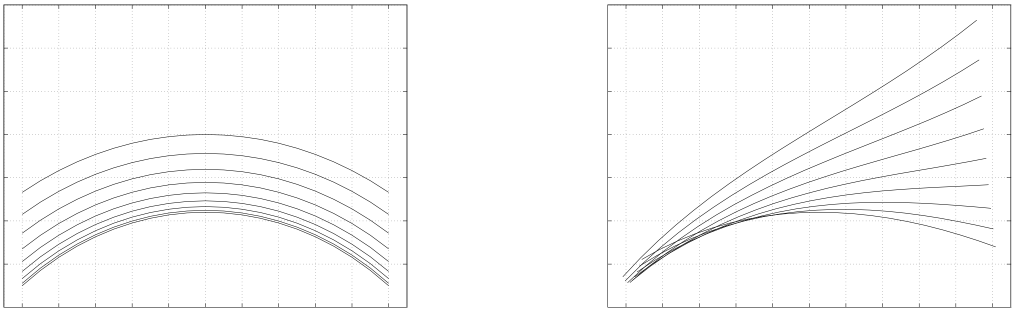


Figure 2: Estimation of a profile of a sherd: a) circle fitting, b) profile construction

The proposed estimation method requires that the sherd needs to be properly oriented before the acquisition. This is done manually in our approach. An initial estimate of the sherd's orientation is given by archaeologists. Then the orientation is improved in a computer assisted orientation process.

The idea of this process is that for a properly oriented sherd the intersection of the sherd's surface with the projected laser plane should form a circular arc. If the sherd is shifted and multiple intersections are estimated in parallel planes, all the intersections should be circular arcs. Diameters of these arcs can differ, but their centers should lie on the same line. After projecting to one particular plane all the arcs should be concentric. This situation is illustrated in Figure 3(a). If the sherd's orientation is bad, the intersections form a different pattern. An example of such situation is depicted in Figure 3(b). The intersections estimated for a particular orientation of a sherd are visually inspected on a computer display. If they do not form a set of concentric circular arcs, the sherd's orientation is manually improved and the intersections are updated for the new position. These two steps are repeated until the proper orientation of the sherd is found.



(a) (b)

Figure 3: Computer assisted orientation process: estimated intersections for properly (a) and badly (b) oriented sherd

After the sherd has been oriented, its profile is estimated. First, a range image of the sherd is acquired. Next, the intersections detected for each projected laser plane are extracted. Based on the idea that these intersections should form circular arcs, each intersection is fitted by a circle. The fitting method described in [8] is used. Finally, the profile of the sherd is acquired.

The profile can be constructed directly from radii of the fitted circles. Unfortunately, such profile will be accurate only if the circles are fitted to error-free input data. If the information on the input range image is degraded by systematic errors and noise, the profile needs to be estimated in a more robust way. We have applied a method based on the following idea: All centers of the fitted circles should (theoretically) lie on the same line — the axis of rotation. This is not true for noisy data, but in that case the axis can be estimated by fitting a line to a set of the centers. After the rotation axis has been acquired, the profile is constructed by a projection of the input range data with respect to this axis. Together with a better stability against noise this approach also improves robustness of the estimation for imperfectly oriented sherds.

3 Experimental Results

The proposed method has been tested in several experiments. Robustness and stability of the method was evaluated on synthetic data. A model of a sherd depicted in Figure 4(a) was used. It can be seen that the model was degraded by noise to improve reality of the input data. The estimated sherd's profile is shown in Figure 4(b). The profile constructed directly from radii of the fitted circles is depicted on the left. After the fitting the sherd's rotation axis was estimated and the profile was corrected. The final result is depicted on the right.

Since sherds need to be oriented before the estimation, sensitivity of the method to the precise orientation of a sherd was evaluated in the next experiment. The same "synthetic" sherd was used, but now inaccuracies in its orientation were simulated in the acquisition. Results are presented in Figure 5. Figure 5(a) depicts several profiles estimated under different orientation errors ranging from 0 to 20 degrees, whereas Figure 5(b) shows the average estimation errors for the same range of orientation inaccuracies.

The proposed method was also tested on a real pottery. A simple range finder consisted of a laser and a CCD camera connected to a PC-compatible computer has been used in our experiments. More details on this range finder can be found in [4]. One example of an investigated pot and its estimated profile is presented in Figure 6.

From the experiments follows that our method of profile estimation is stable and robust against noise. On the other hand, the method is fairly sensitive to the precise orientation of a sherd before measurement. This is the reason why the orientation is done manually based on expert knowledge given by archaeologists. Because an additional computer assisted orientation process is used, sherds can be oriented with errors smaller than 10 degrees. As a result, a profile of a sherd can be estimated with an error about 2–3 millimeters.

4 Conclusion

In this paper, a method for the profile estimation of rotationally symmetric objects based on their fragments was presented. In particular, fragments of archaeological pottery (sherds) were considered. For the estimation sherds need to be oriented properly. The orientation is done manually in a computer assisted orientation process. A model for an intersection between the laser plane and the surface of the sherd was built using these constraints. Regarding the model an active triangulation technique for the profile estimation was proposed. The method uses only one range image of the sherd without a construction of its 3-D model. The method is simple and, consequently, stable and robust with accuracy sufficient for archaeological requirements.

Acknowledgement

This work has been partially supported by the Grant Agency of the Czech Republic under the grant No. 102/95/1378. Radim Halíř also acknowledges partial support by the Austrian Science Foundation (FWF) under the grant No. P09954-SPR. The authors are grateful to Christian Menard, Walter Kropatsch and Pavel Krsek for fruitful discussions.

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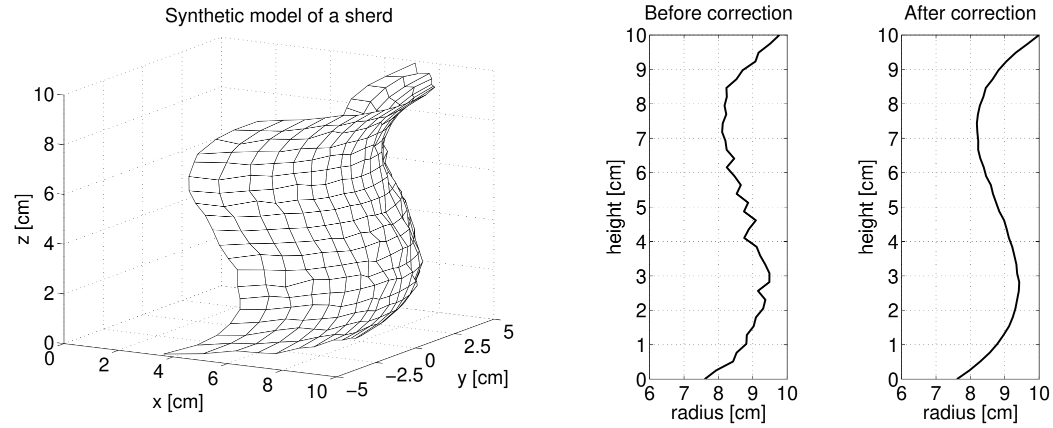
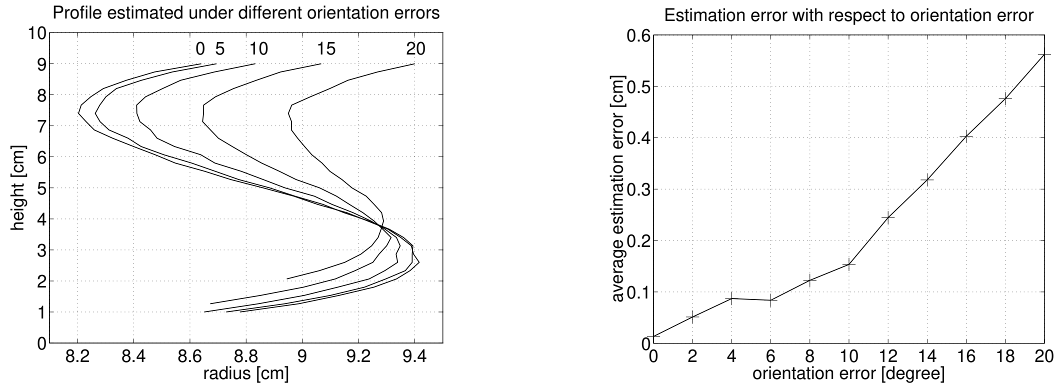


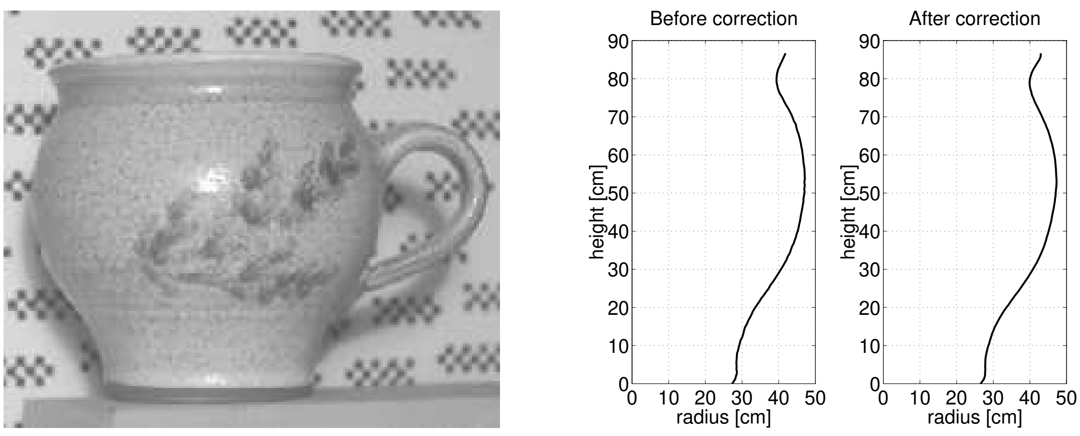
(a) (b)

Figure 4: Profile estimation applied to synthetic data: a) model of a sherd, b) estimated profiles



(a) (b)

Figure 5: Sensitivity of the estimation to the precise orientation of a sherd: a) profiles estimated for an inappropriate oriented sherd (the corresponding orientation errors in degrees are given above each profile); b) average estimation errors with respect to the orientation error



(a) (b)

Figure 6: Profile estimation applied to a real pot: a) image of the pot, b) estimated profiles