On 3d Modelling of Archaeological Sherds

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ABSTRACT

Every archaeological excavation must deal with a vast number of ceramic fragments. The documentation, administration and scientific processing of these fragments represent a temporal, personnel, and financial problem. We are developing a documentation system for archaeological fragments based on their profile, which is the cross-section of the fragment in the direction of the rotational axis of symmetry. Hence the position of a fragment (orientation) on a vessel is important. To achieve the profile, a 3d-representation of the object is necessary. This paper shows an algorithm for registration of the front and the back views of rotationally symmetric objects without using corresponding points. The method proposed uses the axis of rotation of fragments to bring two range images into alignment.

1. INTRODUCTION

Ceramics are one of the most widespread archaeological finds and are a short-lived material. This property helps researchers to document changes of style and ornaments. Therefore, ceramics are used to distinguish between chronological and ethnic groups. At excavations a large number of ceramic fragments, called sherds are found. These fragments are photographed, measured, drawn (called *documentation*) and classified. Up to now documentation and classification have been done manually which means a lot of routine work for archaeologists and a very inconsistent representation of the real object.

None of the prototype systems developed so far to automate the documentation could satisfy the requirements of the archaeologists since the amount of work for the acquisition was not reduced. Therefore, we developed an automated 3d-object acquisition system with respect to archaeological requirements [8]. With the help of the 2.5d-range images [5] achieved from the acquisition system, a 3d-object model has to be constructed in order to determine the profile.

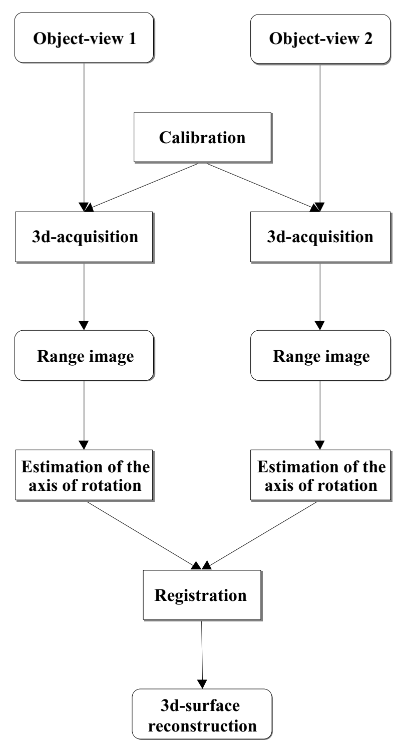

Figure 1: Overview on 3d-reconstruction from two object views.

Archaeological pottery is assumed to be rotationally symmetric since it was made on a rotation plate. With respect to this property the axis of rotation is calculated using a Hough inspired method [10]. To perform the registration of the two surfaces of one fragment, we use a-priori information about fragments belonging to a complete vessel: both surfaces have the same axis of rotation since they belong to the same object.

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Figure 1 gives an overview of a 3d-surface reconstruction from two object views and also shows the structure of this paper. The first step consists of sensing the front- and backside of the object (in our case a rotationally symmetric fragment) using the calibrated 3d-acquisition system. The resulting range images are used to estimate the axes of rotation, shown in Section 2. Section 3 presents the proposed registration method for the surface reconstruction and results are presented in Section 4. We conclude the paper with a discussion of the results and give an outlook on future work.

2. ESTIMATION OF AXES OF ROTATION

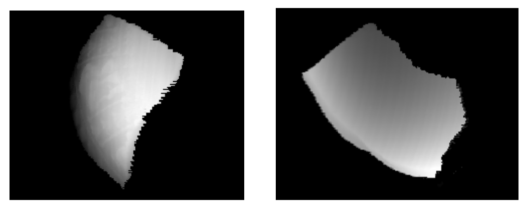
The acquisition system consists of a LCD640 projector and a CCD camera. The acquisition method for estimating the 3d-shape of a sherd is shape from structured light, which is based on active triangulation. The projector projects stripe patterns onto the surface of the objects. With the help of the known orientation parameters of the acquisition system, the 3d-information of the observed scene point can be computed using the triangulation principle. Two range images of one fragment (the front- and the backview) are computed and have to be registered.

The approach exploits the fact that surface normals of rotationally symmetric objects intersect their axis of rotation. Since we have an object of revolution, an archaeological vessel made on a rotation plate, we can suppose that all intersections of the surface normals are positioned along the axis of symmetry.

For each point on the object the surface normal has to be computed. A planar patch of size $s \times s$ can be fitted to the original data using the Minor Component Analysis [7]. The axis of rotation is determined using a Hough inspired method [10]. In order to determine the axis of rotation all surface normals are clustered in a 3d Hough-space: All the points belonging to a line are incremented in the accumulator. Hence the points belonging to a large number of lines (like the points along the axis) will have high counter values and are called maxima. The line formed by the maxima is estimated using the PCA or Principal Component Analysis [6]. Using this technique outliers introduced by noisy range data or discretization errors, can be avoided, since in Hough-space wrong data points are in the minority and do not build a maximum.

3. RANGE IMAGE REGISTRATION

One of the most commonly used algorithms for registering is the *Iterative Closest Point (ICP)* algorithm, based on Besl & Mckay [1]. The basic algorithm consists of calculating the closest points on the surface (which generally is a triangulated surface). Next, the transformation is calculated and applied. The process of calculating the closest points is repeated until the termination criteria are met. Random sampling, as well as least median of squares estimator can be used as termination criteria. Prediction can also be used to speed up the process of registration (refer to [1] for more details). Further information on registration and integration of multiple range image views can be found in [3], [4], [2], and [9].



(a) (b)

Figure 2: The two views of a fragment.

Fragments of vessels are thin objects, therefore 3d-data of the edges of fragments are not accurate and this data can not be acquired without placing and fixing the fragment manually. Ideally, the fragment is placed in the measurement area, a range image is computed, the fragment is turned and again a range image is computed. Figure 2 shows the front- and back- view of a fragment. Since there are no corresponding points, we use a model-based approach. Both surfaces have the same axis of rotation since they belong to the same object and therefore we calculate the axis of rotation of each view (Figure 3a) and bring the resulting axes into alignment (Figure 3b).

Both surfaces should have approximately the same profile; i.e. the thickness of the fragment should be constant in the average to avoid intersecting surfaces (Figure 3c). The correct match is calculated by iteratively minimizing the error δ which expresses the mean deviation to a standard distance of the two surfaces in the direction of the rotational axis. Finally, the intensity images of both surfaces can be mapped onto the registered 3d-object in order to display the fragment with its original properties. Figure 3d shows the result for synthetic range data

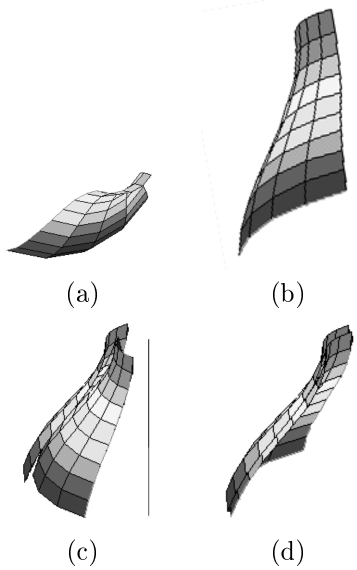


Figure 3: Registration steps using synthetic data.

with 50 surface points for each view. The computed distance between the inner and the outer surface is 0.42mm with variance of 0.059mm. The registration error is small (δ=0.13mm, the mean square errors between the original and the computed axes are 0.26mm and 0.31mm respectively).

4. RESULTS

We tested our method on synthetic range images of a synthetic fragment (thickness 1.5mm) with approx. 7000 surface points each where we had a registration error δ=0.016mm. In comparison to the previous result the registration error is smaller since there are more surface points and therefore the computation of the rotation axis is better.

To find out if the method is working on real data we used a totally symmetric small flowerpot with known dimensions and took a fragment which covered approximately 25% of the original surface. The range images of the front- and back-view consisted of approximately 10.000 surface points each (Figure 4a,b). The mean distance d between the surfaces is 5.64mm and the registration error δ=1.42mm. The distribution of the registration error δ for the flowerpot is shown in Figure 5a. The registration error increases towards the top of the pot, because of the irregularity of the distance between the surfaces at that region since the flowerpot has an edge (upper border) where inner and outer surface are not parallel.

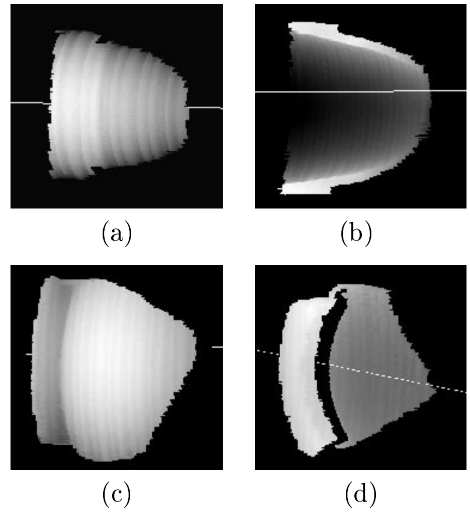


Figure 4: Front- and back-view and their axis of rotation of a flowerpot (a,b) and an archaeological fragment (c,d).

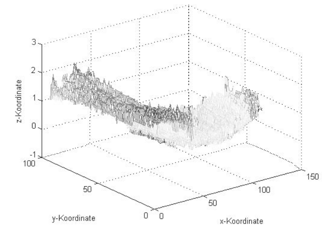
Figure 4c and d show the front-view, back-view and the axis of rotation of a real archaeological fragment. Registration tests with this fragment resulted in registration errors of approximately δ=1.7mm and a mean distance of d=5.8mm. Figure 5b shows the distribution of δ of a registered archaeological fragment. Marginal peaks are caused by shadow regions of the back-view (see (Figure 4d) at the border of the fragment, where either no range data is processed or the range information is unreliable. The increase of the registration error δ reflects the uneven surface of the fragment.

Table 1 gives an overview of the presented results. It shows the number of points of the back- and front-view and the estimated registration error δ. The increase of δ between the synthetic and real data tests is caused by the error in the determination of the rotational axis.

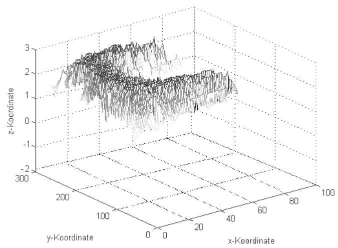
Data type	points back	points front	error δ [mm]
synth.	50	50	0.13
synth.	6674	6674	0.016
real	10191	9619	1.42
real	31298	37176	1.72

Table 1: Results of the registration process.

Further problems that arise with real data are symmetry constraints, i.e. if the surface of the fragment is too flat or too small, the computation of the rotational axis is ambiguous (worst



(a)



(b)

Figure 5: Distribution of δ for registered flower-pot (a) and archaeological fragment (b).

case: sphere) which results in sparse clusters in the Hough-space which indicate that the rotational axis is not determinable.

5. CONCLUSION AND OUTLOOK

We have proposed a prototype system for registering the front- and back-view of rotationally symmetric objects from range data. The work was performed in the framework of the documentation of ceramic fragments. For this kind of objects pair-wise registration techniques fail, since there are no corresponding points in the range images. We demonstrated a technique that computes and uses the axis of rotation of fragments belonging to the same vessel to bring two views of a scene into alignment.

The method has been tested on synthetic and real data with reasonably good results. It is part of continuing research efforts to improve the results from various range images since the technique depends on the rotational symmetry of the objects.

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