Range Image Registration of Rotationally Symmetric Objects

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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. Therefore, we construct a documentation system for archaeological fragments to form the basis for a subsequent semi-automatic classification and reconstruction. The basis for classification and reconstruction is the 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.

Since fragments usually have a front- and backside, a registration of different range images has to be performed. This paper shows an algorithm for registration of the front and the back views of rotationally symmetric objects without using corresponding point. The proposed method uses the axis of rotation of the viewed objects 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. Furthermore, ceramics are used in the economic history to show trading routes and cultural relationships.

At excavations a large number of ceramic fragments, called sherds are found. These sherds are photographed, measured, drawn (called *documentation*) and classified. The purpose of *classification* is to get a systematic view of the material found (if every piece would be treated as unique, this would lead to the wood-for-the-trees syndrome due to the vast amount of information), to recognize types, and to add labels for additional information as a measure of quantity.

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. First, there may be errors in the measuring process. (Diameter or height may be inaccurate), second, the drawing of the fragment should be in a consistent style, which is not possible since a drawing of an object without interpreting it is very hard to do.

Because the conventional method for documentation is unsatisfactory, the search for automatic solutions began early (see [Gat84,WK85,Ste89] for some examples). None of the prototype systems developed could satisfy the requirements of the archaeologists since the amount of work for the acquisition was not reduced. In some cases it was even increased. Furthermore, the accuracy of acquisition was not as high as expected. Therefore, we developed an automated 3d-object acquisition with respect to archaeological requirements [MS96,SM96].

With the help of the 2.5d-range images [Mar86] achieved from the acquisition system, a 3d-object model has to be constructed in order to have the complete shape description of the sherd for the determination of the profile. Two views of the fragment (front- and the back-view) have to be aligned in order to get a 3d model. This process is called registration.

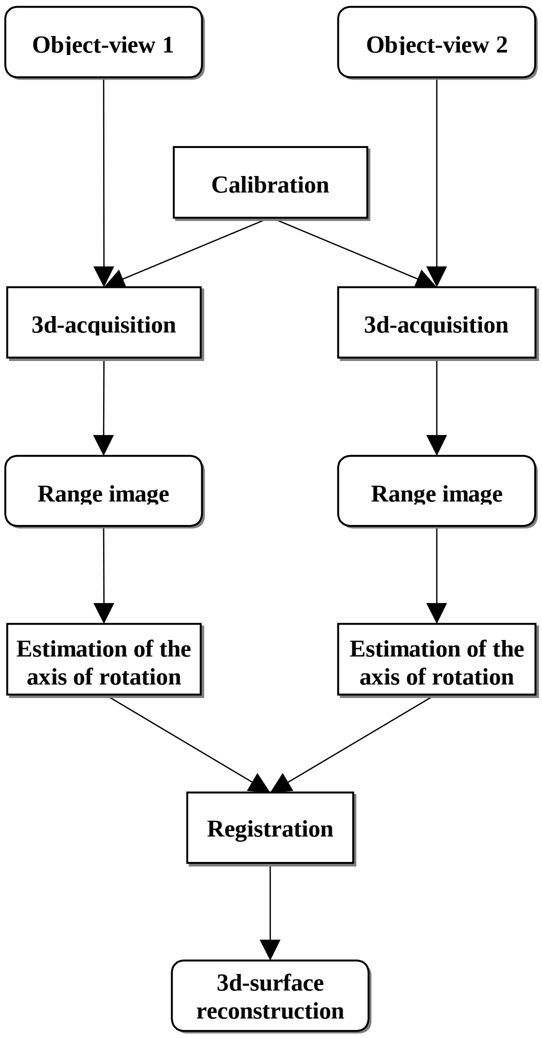


Fig. 1: Overview on 3d-reconstruction from two object views

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 [YM97]. To perform the registration of the two surfaces, 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. We can register the range images by calculating the axis of rotation of each view and bringing the resulting axis into alignment. Fig.1 gives an overview of a 3d-surface reconstruction from two object views and also shows the structure of this paper.

Prior to the sensing of the front- and backside of the object (in our case a rotational symmetric sherd) a calibration of the 3d-acquisition system has to take place (Section 2). The resulting range images are used to estimate the axes of rotation, shown in Section 3. Section 4 presents the proposed registration method for the surface reconstruction. We conclude the paper with a discussion of the results and an outlook on future work.

2. Acquisition System

The acquisition system consists of a LCD640 [Wol95] projector and a CCD camera. In order to analyze and process digital images it is important to know the position of the sensor in a reference co-ordinate system. In the process of calibration the parameters to describe the geometrical model are estimated.

The acquisition method for estimating the 3d-shape of a sherd is shape from structured light, which is based on active triangulation. A very simple technique to achieve depth information with the help of structured light is to scan a scene with a laser plane and to detect the location of the reflected stripe. The depth information can be computed out of the distortion along the detected profile.

In order to get dense range information the laser plane has to be moved in the scene. Another technique projects multiple stripes simultaneously onto the scene. In order to make it possible to distinguish between stripes they are coded (Coded Light Approach) either with different brightness or different colors [KB87]. A robust encoding method is the time-space encoding of projection directions. In one method a projection of time encoded laser dots was used [AA79]. This method was improved by [Wah84,ISM84] by using time space encoding of stripes by projecting a sequence of *n* stripe patterns onto the scene.

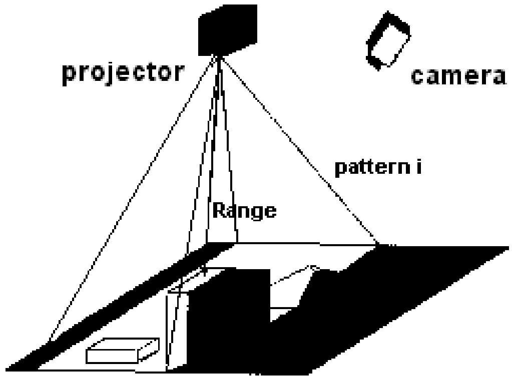


Fig. 2: Configuration with light projector, camera and object

In our acquisition system the stripe patterns are generated by a computer controlled transparent Liquid Crystal Display (LCD 640) projector. The light patterns allow the distinction of 2^n projection directions. Each direction can be described uniquely by a *n*-bit code. A CCD-camera is used for acquiring the images (Fig. 2).

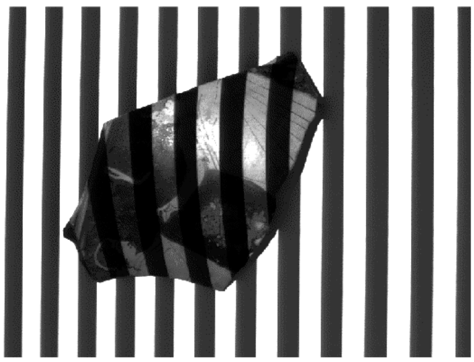


Fig. 3: Fragment with stripe patterns

The projector projects stripe patterns onto the surface of the objects (Fig. 3). In order to distinguish between stripes they are binary coded. The camera grabs gray level images of the distorted light patterns at different times. With the help of the code and the known orientation parameters of the acquisition system, the 3d-information of the observed scene point can be computed. This is done by using the triangulation principle.

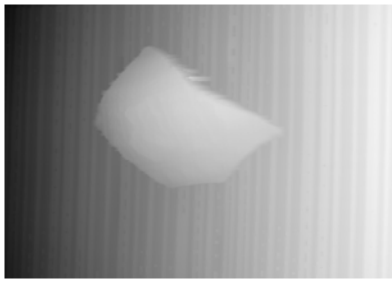


Fig.4: Range image of a fragment

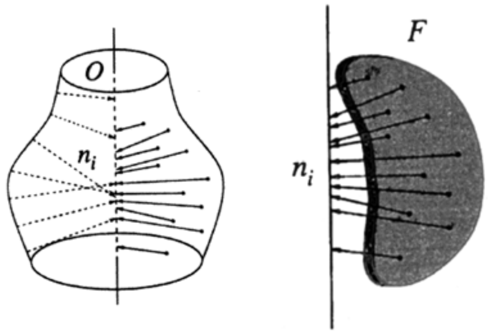
The image obtained is a 2D array of depth values and is called a range image (Fig.4).

3. Estimation of axes of rotation

The approach exploits the fact that surface normals of rotationally symmetric objects intersect their axis of rotation. The basis for this axis estimation is a dense range image provided by the range sensor. If we have an object of revolution, like an archaeological vessel made on a rotation plate, we can suppose that all intersections n_i of the surface normals are positioned along the axis of symmetry a.

This assumption holds [Hal97] for a complete object (Fig.5a) or even for its fragment (Fig. 5b). For each point on the object the surface normal has to be computed. A planar patch of size *s x s* can be fitted to the original data using the Minor Component Analysis [OXS92], which minimizes the distance between the points of the surface and the planar patch in an iterative manner in order to compute the optimal value of the normal and discard outliers.

The axis of rotation a is determined using a Hough inspired method [YM97]. For each point on the object, the surface normals n_i are computed using Minor Component Analysis. In order to determine the axis of rotation a all surface normals n_i are clustered in a 3d Hough-space: All the points belonging to a line n_i 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. All the points in the accumulator with a high counter value are defined as maxima.



(a) (b)

Fig. 5: Surface normals n_i of a rotationally symmetric object *O* intersect the axis of rotation *a*; this should be true for complete objects (a) and for its fragments (b) (from[Hal97]).

In the next step the line formed by the maxima has to be estimated. There are different techniques to solve this problem. The PCA or Principal Component Analysis [Oja83] is a very popular method, which is used in our case. We have an a-priori knowledge: the maxima points are distributed according to a line (the axis of rotation). The PCA will determine the axis of maximal variance, which is in fact the axis of rotation. The accumulator maxima are taken as candidate points for the estimation of the axis of rotation. 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.

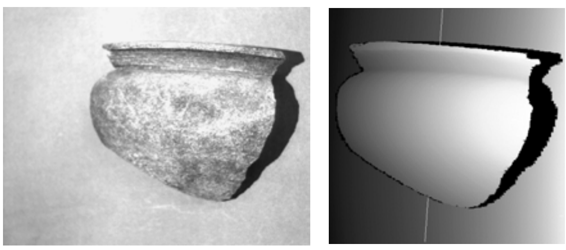


Fig. 6: Intensity image (left) and range image (right) of a fragment with rotational axis of the front-view

Figure 6 shows the result for a front-view of a fragment. On the left hand side of Figure 6 the intensity image of the fragment is shown, on the right hand side the range image with the estimated rotational axis are depicted.

4. Range Image Registration

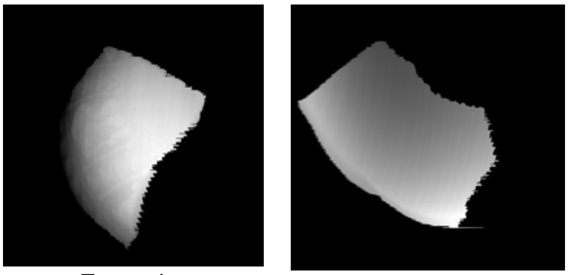
Registration is the process of aligning two or more views of an object, in our case the front- and the back-view of the fragment. These views can be represented as either intensity images or range images. Range information about the object achieved with coded light approach.

The task of building full 3d-models is a more difficult problem, since we have two depth maps to register and we have no prior knowledge about the shape of the object. One simple method is to use a calibrated turntable upon which the camera is fixed, as described in [Sze94]. Even though the turntable method described above is good at creating 3d-models, there is still the question of getting the bottom of the object sitting on the turntable. So the bottom of the object needs to be scanned in and then registered.

One of the most commonly used algorithms for registering is the *Iterative Closest Point (ICP)* algorithm, based on Besl & Mckay [BM92]. 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 [BM92] for more details).

Further information on registration and integration of multiple range image views can be found in [DWJM96, DWJM98, CM92] and [TMY96].

In our case we can not use pairwise registration techniques like the *ICP*, since we do not have corresponding points (i.e. points of the object that are present in both images) in our range images. 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. To perform the registration of the two surfaces, 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. Furthermore, the distance of the inner surface to the axis of rotation is smaller than the distance of the outer surface. Finally, both surfaces should have approximately the same profile; i.e. the thickness of the fragment should be constant.



Front view   Back view

Fig. 7: The two views of a sherd

Fig. 7 shows the front- and back- view of a fragment. The goal of the registration is to find the transformation that relates these two views to one another, thus bringing them into alignment so that the two surfaces represent the object in 3d [AA71]. Since there are no corresponding points, we use a model-based approach. No point to point correspondences are required to determine the interframe transformation needed to express the points from each view in a common reference co-ordinate system [VA86].

We register the range images by calculating the axis of rotation of each view (Fig. 8a) and bringing the resulting axes into alignment (Fig. 8b).

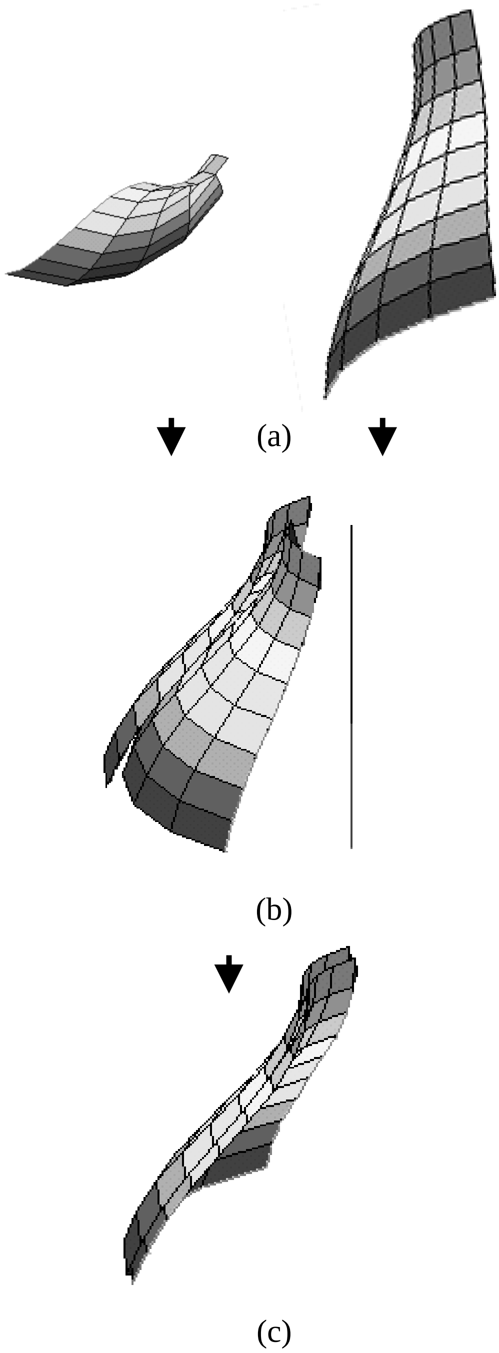


Fig. 8: Registration steps using synthetic data

Knowing the surface normals of all surface patches we transform them into a common reference co-ordinate system. In the next step we have to align the surfaces of the objects to avoid intersecting surfaces (Fig. 8c). 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 8 shows the result for synthetic range images. The computed distance between the inner and the outer surface is 0.42mm with variance of 0,059. The registration error is small (the mean square errors between the original and the computed axes are 0.26 and 0.31 respectively, the registration error 0.25).

We are currently performing tests on real data. Problems that arise with real data are symmetry constraints, i.e. if the surface of the sherd is too flat or too small, the computation of the rotational axis is ambiguous (worst case: sphere). Therefore, we are currently working on defining constraints concerning curvature and minimum size of sherds.

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 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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