CLASSIFICATION OF ARCHAEOLOGICAL FRAGMENTS USING A DESCRIPTION LANGUAGE

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ABSTRACT

This paper presents an application of 3d-reconstruction and graph theory in the field of archaeology. The classification and reconstruction of ancient pots and vessels out of fragments (so-called sherds) is an important aspect of archaeological research work. Up to now this is a time consuming, inaccurate, and subjective task which leads to tons of unclassified fragments in archives. Computer aided classification could help to get a better understanding of ancient cultures, since all data of an excavation would be accessible to the public, not only selected parts as it is now.

We propose a bottom-up strategy to classify fragments. The profile section (which is a section a the fragment in the direction of the rotational axis) is segmented into its primitives (with certain properties like length) and relations among this primitives (like position and curvature of connecting points). These primitives and the relations form a description language, different profiles have different descriptions.

1 INTRODUCTION

Every archaeological excavation is confronted with a vast number of ceramic fragments. The documentation, administration and scientific processing of these fragments presents a temporal, personnel and in connection with the above, a financial problem. Many excavation projects have been completed for many years, yet due to these problems, their findings have yet to be published (see for instance [7]). Scientific evaluation in archaeological practice often suffers due to extensive amounts of time required for the documentation and administration of ceramic finds. Many publications do little more than present the drawings, descriptions and determinations of the objects found.

Up to now archaeological documentation has been done by hand 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. The third process, grouping or classifying is also very difficult task, there are several attempts for a reliable method of classification, none of them is widely accepted.

A computer aided solution to the problem must integrate several different sources of information:

1. 3d- acquisition of excavated fragments including 3d-shape, texture, and color.
2. An archive-database collecting all the knowledge relevant to perform the classification as done by a human expert.
3. Strategies that relate the acquired raw data to the high level classification.

The solution to the above mentioned 3 part problems in fragment classification integrates the 3d- acquisition system, the archive-database and the classification strategy into a so-called description language, a data representation that allows to perform the classification.

A description language that was originally designed to solve 2d- automatic visual inspection problems [14] is applied and extended in order to solve the 3d- classification. The description language holds all features of the fragment as primitives and all properties among features as relations. Primitives are further subdivided into part-models (or part-primitives), the consistency between part-primitives is established by relations among part parameters. Similarity among part-primitives and fitness criteria allow a re-integration from these parts. Figure 1 shows an archive drawing of a fragment with it's profile section divided in three primitives.

In the reconstruction phase, part similarities of profiles can be detected and complete pots can be reconstructed based on the already stored data in the description. The bottom-up design using a description language for the reconstruction process makes a detection of similar fragments in the database possible, because the matching process starts with the comparison of the entire primitives with already existing relations.

In archaeology a number of papers tackle the problem of objective manual classification, although no standard

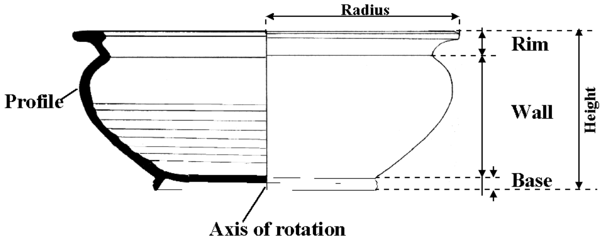

Figure 1: Profile with known primitives.

can be determined, each country and region has its own standard (see for instance [1, 6, 4]). One computer based approach [15] tried to give a solution to the classification problem by approximate cross section by 2d curves, due to the errors introduced by the acquisition system and the curve fitting this solution was not accepted by archaeologists since matching profiles could not be found robustly. In contrast to this subjective approaches, our primitive-based approach gives the possibility to relate different profiles to common primitives or sub-primitives. Therefore it is possible to reconstruct different profiles out of one primitive, the expert has the possibility to choose the most relevant.

In order to standardize the classification, which is based on the fragment's structure, it can be divided into two main parts, shape features and material properties. The classification of shape defines the process where archaeologists distinguish between various features like the profile, the dimensions of the object like diameter and type of surface, whereas the classification of material copes with different characteristics of a fragment like the clay, color and surface properties. The profile is defined as the intersection of the fragment with the plane going through the axis of rotation of the pot to which the fragment belongs. Rotational symmetry of the original pot is assumed. The profile of the fragment is used to reconstruct the original pot from its part assemblies. It is subdivided into 3 main categories: Rim, wall, and base (ordered from the top of the vessel to the bottom). Each of the main categories is subdivided into sub-categories.

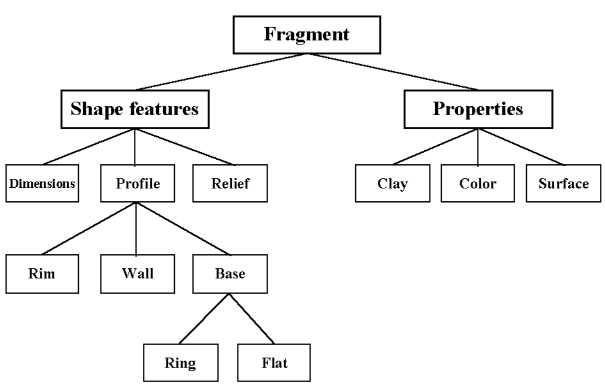

Figure 2: Fragment structure.

The profile analysis has two purposes; reconstruction and volume determination and classification for a retrieval of fragments of the same type. The reconstruction procedure works well if the size of the fragment covers a large part of the original pot in the vertical direction. The profile is rotated by the original rotation axis, thus measurements like volume can be estimated. However, if only small fragments (in respect to the vertical size) are available, a reconstruction out of the fragment is not possible. In this case, the fragments have to be classified correctly in order to retrieve matching fragments. A decision model is necessary to make a reconstruction out of small fragments possible.

2 3D ACQUISITION

The first step in automating the classification of archaeological finds is the construction of an automated acquisition system in order to get a digital representation of the object. We constructed a 3D measurement system for archaeological fragments which combines stereo, coded light, and laser acquisition techniques. This can be seen as an extension of previously reported prototypes [9, 13] (see these papers for a comparison of the presented system to other archaeological acquisition systems) in order to achieve the profile section automatically. An archaeological fragment is placed in the measurement area. The acquisition method used for estimating the 3D-shape of a fragment is called shape from structured light, which is based on active triangulation. The technique projects multiple stripes at a time onto the surface of the object. In order to distinguish between stripes they are coded either with different brightness or different colors [2]. A robust encoding method is the time-space encoding of projection directions. In this work the coded light approach is used. This method uses time space encoding of stripes by projecting a sequence of n stripe pattern onto the scene [8, 16]. The range information is achieved by using the triangulation principle. Two cameras are positioned on the left and right border of the measurement area, the structured light projector is positioned above the measurement area. Furthermore two lasers which are positioned on the left and the right side are used for generating a specific profile-section of the fragment.

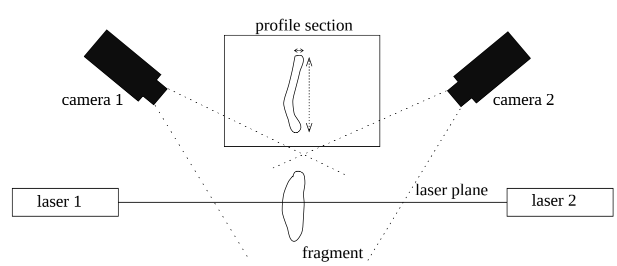

Figure 3: Acquisition system using 2 lasers.

These range images together with the intensity image are used to receive a realistic 3D model of a fragment.

Profile sections can be computed directly by using the two laser method. By using the 3D model archaeologists are able to perform 3D measurements on the surface of the objects interactively. In order to compute a profile section we used the laser approach since up to now we only have the range information of the top view of the fragment. To construct a profile section it is necessary to determine the thickness of the fragment and this can only be achieved if front and back-view of the fragment are registered. To overcome this registration problem and to get profile sections quickly we installed this two laser solution. The two lasers are positioned in order to produce one light-plane. This light-plane intersects the fragment and the so created light-stripe is observed by the two CCD cameras. Figure 3 shows the constructed laser acquisition prototype.

3 CLASSIFICATION

The 3D model of the fragment is the basis for the reconstruction method. Using this model, the profile-section of the fragment can be generated for a given direction [10]. This profile is then used for classification and reconstruction of pots. One main goal in the classification process is to find different fragments which belong to the same pot in order to reconstruct the original pot, both in electronic and "natural" ways (the parts are glued together).

Using already archived profile-sections of fragments, relations to pots can be established. In order to reconstruct complete pots, profiles with similar attributes are to be found in the archive database. Until now, archaeologists try to match a complete profile section to all existing profiles in a database using constraints like excavation layer, color, clay etc. This procedure is very time consuming and for short profiles the probability to find a match in long profiles is low. This procedure is a top-down strategy, since the complete profile section is used as basis for the similarity algorithm.

The second method used in this work is called bottom-up strategy. The profile-section is first segmented into its primitives (rim, wall, base). These 3 segments of the profile are stored in a so-called description of the profile. To accomplish the goal of classification primitives are further subdivided into part-models (or part-primitives), the consistency between part-primitives is established by relations among part parameters. Similarity among part-primitives and fitness criteria allow a re-integration from these parts.

The profile is part of the fragment model which can be separated into fragment structure, description and profile: The fragment structure is formed by its shape features (or geometric features like the profile) and its properties (or material like clay) as shown in Figure 2. The description of the fragment is structured in a description language consisting of primitives and relations. Primitives are a representation of shape features, relations represent the properties. The actual profile contains features which are a representation of shape features. Since the description is used to perform the classification and reconstruction, features interact with the representation of the fragment structure in the description.

From the description language point of view, the modeling can be interpreted as a syntactic pattern recognition approach in which the primitives are transformed into the vocabulary and the relations are transformed into a grammar [5]. This approach makes use of the idea of shape decomposition, it divides complex shapes into simple elementary units, i.e. primitives. This can be seen as an application of semantic networks [11, 3], since semantic networks are labeled, directed graphs where nodes represent objects, sub-objects, or shape primitives and arcs represent relations between them. A set of attributes that describe different features is attached to each node; a set of attributes that describe different properties is attached to each arc. Once the fragment is transformed to this representation all operations for classification and reconstruction can be executed on this graph structure. The advantage of a description language lies in the uniqueness of representation, different fragments result in different descriptions, similar fragments result in similar descriptions. The shape is subdivided into c different shape primitives (such as profile, diameter and the like). For each of these shape primitives n different sub-primitives (such as lip, body and the like) are defined. Since manual segmentation of the profile varies tolerances and weights are included in the description.

For a given profile all primitives are represented in the description of the given profile. Therefore the profile has to be segmented into the individual primitives. Since this segmentation is based on the expert knowledge, this procedure is carried out by archaeologists manually. This segmentation is carried out for all profiles to be classified.

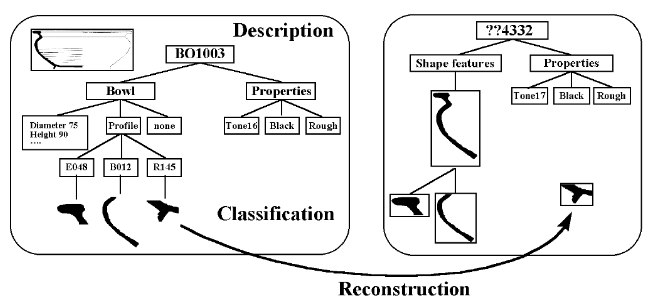

Figure 4: Retrieval of similar fragments.

Figure 4 describes an example for the retrieval. Each fragment has a unique number when archived. Together with all attributes the fragment is stored in the description. The left side of Figure 4 shows a profile which was classified as bowl and separated into edge (E048), border (B012), and ring-base (R145). These primitives are the basis for the classification and reconstruction process. On the right hand side of Figure 4 a fragment which is not yet classified is depicted, thus the type of the pot is not yet known. The profile is manually segmented into its primitives by an archaeologist and the according attributes like color, surface, and dimensions are determined. In order to classify the fragment (find the pot in the database that matches the fragment) the generated description is compared with already existing descriptions. If the profile primitives of the fragment can be found in the description and other attributes match within a given tolerance the type of the fragment can be classified as bowl. Furthermore missing parts of the fragment (like the base in this case) can be reconstructed based on the already stored information.

4 CONCLUSION AND OUTLOOK

In archaeology a number of papers tackle the problem of objective manual classification, although no standard can be determined, each country and region has its own standard (see for instance [1, 6]). One computer based approach tried to give a solution to the classification problem by approximate cross section by 2-d curves, due to the errors introduced by the acquisition system and the curve fitting this solution was not accepted by archaeologists since matching profiles could not be found in a robust manner. In contrast to this subjective approaches, our primitive-based approach gives the possibility to relate different profiles to common primitives or sub-primitives. Therefore it is possible to reconstruct different profiles out of one primitive, the expert has the possibility to choose the most relevant.

Furthermore the acquisition and orientation is fully automated, a robust determination of the axis of rotation allows a robust computation of the profile used to classify the fragment. This profile is segmented into primitives. The advantage of this method is that part similarities of profiles can be detected and complete vessels can be reconstructed based on the already stored data in the archive database. The bottom-up design using a description language for the reconstruction process makes a detection of similar fragments in the database possible, because the matching process starts with the comparison of the entire primitives with already existing relations. Future work will be guided towards automated segmentation of the entire profile by creating segmentation rules based the expert knowledge of the archaeologists and the curvature of the profile. Local changes in curvature [12] will be the basis for the required rules for segmenting the profile.

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