

# ANCIENT COINS & CERAMICS - 3D AND 2D DOCUMENTATION FOR PRESERVATION AND RETRIEVAL OF LOST HERITAGE

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## ABSTRACT:

Motivated by the requirements of archaeologists we are developing an automated system for acquisition, documentation and management of daily finds of excavations. These daily finds can be separated into large objects like remainders of architecture and small objects of ancient daily life - like ceramics and coins. Ceramics especially are found in numbers of tens of thousands on virtually every excavation, because ceramics have been in use for thousands of years. Until the present day these finds are documented by manual drawings. There is a similar situation in the case of coins, where manual drawings are often used to abstract them from photographs. Therefore we propose an automated acquisition and documentation system based on digital cameras and structured light for small findings. For ceramics we provide further processing to estimate horizontal cross-sections (profile-lines) for printed documentation, as it is done by manual drawing. For this a proper orientation of the acquired 3D-model is required and automatically estimated based on the assumption that ceramics were made on rotational plates (wheels).

We are aware that ceramics might not always have been manufactured on rotational plates, because the wheel was not invented everywhere as for the example in the Americas. Even though ceramics from such areas appear to be rotational symmetric, we developed a method based on shape and symmetry analysis to determine the manufacturing techniques of ceramics. This helps to answer another archaeological question regarding the technological advance of an ancient culture.

Results for accuracy and performance are shown on real data from recent interdisciplinary projects together with archaeologists from Austria, Germany, Israel and Peru. Furthermore we present preliminary results of the integration of coin classification in our documentation system. Additionally we are currently adapting the London Charter to ensure the intellectual integrity, reliability, transparency, documentation, standards, sustainability and accessibility of the information gathered by 3D-acquisition. Finally a summary and an outlook is given.

## 1 INTRODUCTION

Documentation of ceramics is a main task in archaeology, because ceramics are the most common findings, used and produced in large numbers by humans for several thousands of years. Archaeologists use analysis of ceramics (Leute, 1987) on a daily basis to reveal information about the age, trading relations, advancements in technology, art, politics, religion and many other details of ancient cultures. The same applies to coins, which are found in small numbers, but they have a similar importance, because they can be related to time periods and regions thanks to the embossed information e.g. like well-known emperors.

Both types of finds – ceramics and coins – are typically documented by manual drawings and not photographs, because a draftsman draws only the relevant details of a find. This has to be done, because the finds generally have signs of wear, dirt, corrosion, etc. which tricks the human eye. Furthermore these finds have to be documented properly, because they cannot be brought outside the countries hosting the excavation. Also, due to security issues even local access to the storages of the finds is granted to limited groups of experts.

Therefore we are developing two systems: the first system is an automated system for ceramics documentation to help archaeologists document their finds in an efficient and accurate way, which can be used for further (computerized) research. The second system aims to retrieve finds, which are often stolen from excavations due to their value for collectors. While the first system has

evolved within several national and international projects, the development of the second system has been recently started within *COINS: Combat On-line Illegal Numismatic Sales*-project.

At a first glance these two systems appear to be separate, but they will be united within future work, because the methodologies will be interchanged resulting in a 2D and 3D-framework for documentation and retrieval of small finds. Therefore it must be stressed that the methods for retrieval of stolen coins can be extended and adopted to ceramics to (virtually) retrieve and therefore enable the determination of the context between finds of different excavations.

Therefore the first and main part regards ceramics as described in Section 2 showing basic documentation for daily finds and specialized methods, which help archaeologists to answer more specific questions about ceramics. The second part (Section 3) shows preliminary results of the COINS-project. Finally a summary and an outlook about documentation and preservation of small archaeological findings are given in (Section 4).

## 2 CERAMICS

The basis of documentation of ceramics is a manually drawn horizontal intersection, which is called profile line (Leute, 1987). As the ceramics are found in tens of thousands at virtually every excavation, these drawings require a lot of time, skill and man-power of experts. Therefore we are assisting archaeologists

in interdisciplinary projects (Kampel and Sablatnig, 1999, Cosmas et al., 2001) by using an automated system for acquisition and documentation of ceramics using a 3D-scanner based on the principle of structured light (DePiero and Trivedi, 1996, Liska, 1999).

This section is structured into three parts: First we describe the methods used for basic documentation (Section 2.1), which can be applied on complete ceramics and their fragments. This work is the basis for symmetry-analysis leading to the determination of the manufacturing technique of ancient ceramics, as shown in Section 2.3. Finally Section 2.4 shows an example for processing decorated ceramics for further archaeological research.

## 2.1 ACQUISITION

Regarding documentation of ceramics the basic method applied to unbroken ceramics and fragments of ceramics is the estimation of a profile-line. This is the longest elongation around – or cross-section through – the wall of a ceramic defined by the rotational axis (also called axis of symmetry). The term rotational axis relates to the fact that rotational wheels (plates) have been used for thousands of years for manufacturing ceramics. This assumption can be made especially, but not only for daily finds on archaeological excavations. Therefore we base our work on using the rotational axis to orient a ceramic or its fragment to estimate the profile line as it is done manually by drawings. Furthermore the creation of such manual drawings is a time-consuming task requiring expert-skills and our system will help to dramatically reduce the time for documentation. Figure 1<sup>1</sup> shows an orientated front-view and a manual drawing of profile line of a fragment of a ceramic (also called sherd) found at the excavation at Tel Dor, Israel (Stern, 1994, extended 2000).

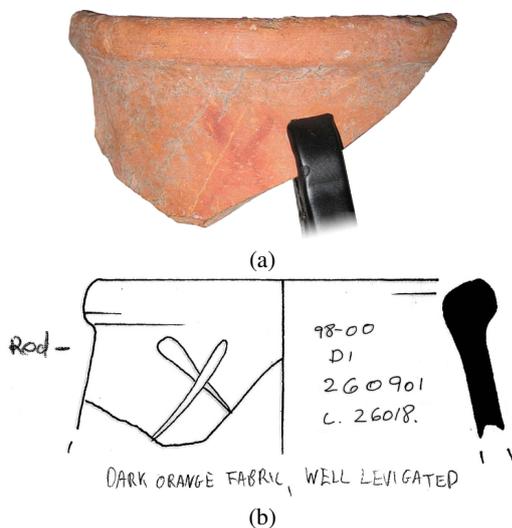


Figure 1: (a) Front-view and manual drawing<sup>1</sup> of a(b) profile-line of a sherd found at the excavations at Tel Dor, Israel.

Therefore the challenging tasks for developing a documentation system for archaeology are to build a system, which is accurate, portable, inexpensive, easy-to-use and robust for all kinds of foreign climate, which can range from desert, to jungle to arctic. This means several technologies like computer tomography and other laboratory equipment is often not suitable for the daily work of archaeologists - especially not for ceramics.

<sup>1</sup>The manual drawing was made available by Ilan Sharon, Hebrew University of Jerusalem.

As photography has already proven its reliability for archaeology, we chose to use a camera and a light-source for 3D-acquisition. Our first prototype (Sablatnig et al., 1991) in our laboratory was based on the principle of structured light (DePiero and Trivedi, 1996). Its predecessor was a digital still camera with a special flashlight called *Eyetratics ShapeSnatcher* (Cosmas et al., 2001). This camera was developed and used in the *3D-MURALE* project (Cosmas et al., 2001).

Nowadays we use 3D-scanners from the *Konica-Minolta Vivid* (Mara, 2003, Mara and Hecht, 2006) product range, because of their resolution ( $\approx 0.1 \text{ mm}$ ), which meets the requirements given by archaeologists for their documentation. Figure 2 shows the setup of our 3D-scanner from recent experiments at the excavations in the Valley of Palpa (Reindel and Cuadrado, 2001), Peru.

Furthermore Figure 2(a) shows the triangulation principle (Mara, 2003) using a laser (bottom) and a camera (top) having a well-known distance and orientation. Additionally the turntable – also shown in this Figure – is used to get a complete 3D-model of the ceramic. The number of 3D-scans depends on the complexity of the ceramic and it typically ranges from two scans for sherds up to eight scans for vessels. The 3D-scans are registered using (Tosovic, 2002) to reassemble a complete 3D-model.

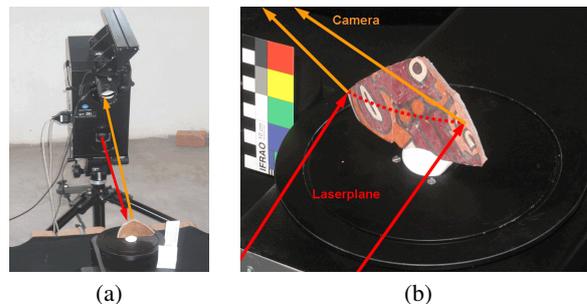


Figure 2: *Konica-Minolta Vi-9i* 3D-scanner (a) projecting a laser-plane (bottom arrow) on to a sherd, while the camera (top) acquires the projection of the laser. Having a well-known distance and orientation of the laser-plane and the field of view of the camera the distance (range) can be estimated. (b) Detail of this setup showing a sherd mounted with plasticine on the turntable, which is used for controlled acquisition of all sides of an object.

## 2.2 PROCESSING

After the registration, noise from dust and other objects like holding devices (e.g. clamps or plasticine) are removed from the 3D-model. Then the orientation is estimated based on the assumption that ceramics are rotationally symmetric objects (Mara, 2003), because they were generally manufactured on rotational plates. The principle of our orientation method is fitting of circle templates (Gander et al., 1994). In comparison to the computerized, but manual method of (Melero et al., 2003) our orientation method can be used fully- and semi-automatic (Lettner et al., 2006). Furthermore our system is capable to store the 3D-model and further archaeological information (e.g. description, photographs, etc.) in a database. For solving the puzzling problems of other – typically industrially manufactured – rotational objects, methods like (Pottmann and Randrup., 1998, Willis, 2004, Oriols, 2004) can be applied. Having an orientated 3D-model a vertical cross-section is estimated using the point of maximum height of the 3D-model. this cross-section is the so-called profile line, which concludes the traditional archaeological documentation.

For comparison with the well consolidated manual approach we acquired 25 sherds given by archaeologists. All these sherds are

considered "small", which means that any sherd smaller than the selected ones, cannot be orientated manually. For further cross-validation the sherds have also been orientated and documented through the use of a *Profilograph* (Utili and Dolmazon, 2002). For comparison of the profile lines from these three ways of documentation, we used the novel method of Thodberg (Thodberg, 2003) for shape matching to estimate the differences between them. This has to be done, because for real data there is no ground truth in general.

Figure 3 shows one estimated profile lines using manual orientation, the *Profilograph* and orientation using circle templates. Further results can be shown in (Mara, 2003). Concluding these results, we could orientate 24 out of the 25 sherds. Comparison of the profile lines between the systems showed, that the systems agree for  $\approx 2/3$  of these sherds, while the remaining  $1/3$  of the profile lines have identical shape, but differing radii and orientation in respect to the rotational axis. The reason is that these sherds are small fragments of large and/or flat vessels (e.g. plates $\approx$ cones).

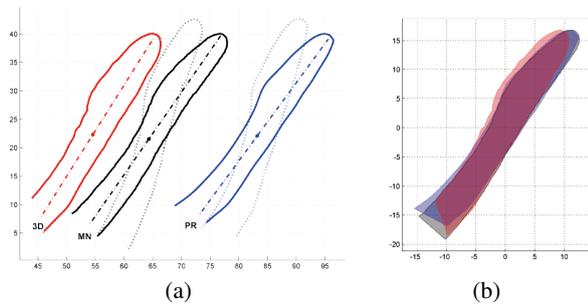


Figure 3: (a) Profile lines estimated by manual orientation (*MN*), the *Profilograph* (*PR*) and using circle templates (*3D*). The dotted profile lines are rotated and (b) shifted by the Thodberg's method for comparison.

As such a rather simple two-dimensional profile line does not reflect any information about the manufacturing quality leading to the manufacturing technique, we decided to enhance our system by giving the archaeologists a tool to gather further information about the acquired 3D-model. These enhancements are shown in the following sections. Figure

### 2.3 SYMMETRY ANALYSIS

As archaeologists are also excavating burial places, where unbroken ceramics or complete sets of sherds are found, we are presenting a method to determine the manufacturing process of ceramics, which reveals information about the technological advancement of an ancient culture. Furthermore this method can be applied, but is not limited to, unbroken or reconstructed vessels.

Technological advancement, is determined by archaeologists between ceramics, that have been produced either on slow or fast turning rotational plates. Another example is an ongoing discussion between archaeologists about the existence of rotational plates for manufacture of ceramics in South America. The general opinion is that in this region the wheel was not invented, therefore ceramics were produced without a rotational plate (wheel) (Wieczorek and Tellenbach, 2002) on the other hand-side there is evidence that rotational plates were used (Carmichael, 1986).

As we use structured light as 3D-acquisition method, we cannot make an assumptions about the internal structure of a ceramic as (Wieczorek and Tellenbach, 2002), but we can estimate the

surface with a high resolution ( $0.1 \text{ mm}$ ). Therefore we can analyze the symmetry and estimate features like deviation of real surfaces in respect to a perfectly symmetrical surface. Such features can help archaeologists to decide about the technological advancements of ancient cultures.

To begin our investigation and answer questions about the manufacturing process of ceramics, we chose to use two modern pots, which were manufactured in a traditional way. Therefore this data can be interpreted as mixture between synthetic and real data, because we used real objects. However, unlike real archaeological fragments, we know how they was produced.

Furthermore we decided to use the method for finding the orientation of a sherd (Mara and Kampel, 2003). We began with the profile line, which can be estimated in a similar way like in case of sherds. The difference is that for complete vessels the bottom plane can be used for orientation, because it is the counterpart for the rotational plate, which defines the (orthogonal) axis of rotation.

We estimated multiple profile lines, which can be overlaid by transforming them into the same coordinate system, where the  $y$ -axis equals the rotational axis. Therefore the distance between profile lines can be estimated. Figure 4 shows the longest profile line and multiple profile lines combined with the side-view, as archaeologists show such vessels in their documentation. In the case of the multiple profile lines, we have estimated that the distance between the profile lines differs and therefore these pots and their profile lines are unique. The maximum distance between two profile lines of the first pot was  $9.8 \text{ mm}$ , whereas for the second pot was  $21.2 \text{ mm}$ .

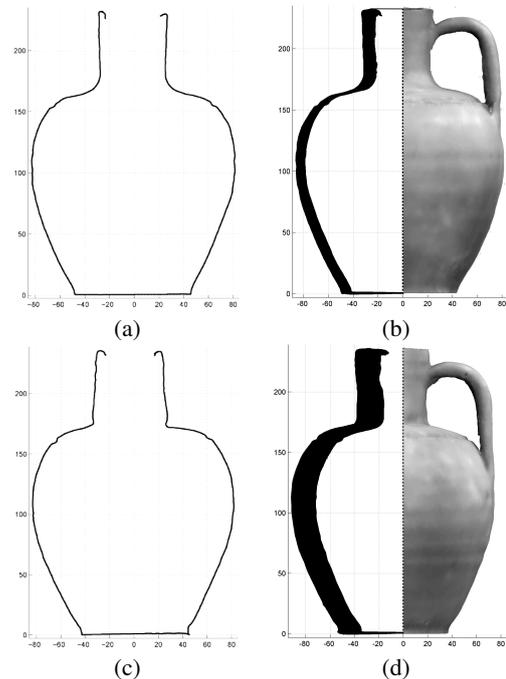


Figure 4: (a,c) Longest profile lines and (b,d) multiple profile lines of modern ceramics, manufactured in traditional way, which are supposed to be identical.

In the multiple profile lines shown Figure 4(c,d), the distance between profile lines, measured parallel to the  $x$ -axis, is not equal. If the profile lines were parallel, this would mean, that the pots have an elliptic (horizontal) cross-section. As it appears, the asymmetry is more complex. Therefore, we chose to analyze the

pots slice-by-slice along the rotational axis, presumed as orthogonal to the bottom plane.

Figure 5(a,c) shows horizontal intersections, which have been applied with a distance of 10 mm along the rotational axis. The distance of 10 mm corresponds to the manufacturing process, which has left traces in the form of rills as seen along the right hand sides of Figure 4(b,d). These rills are spaced 10 mm, which corresponds to the width of the finger or tool used to "grow" the pot along the axis of the rotational plate. The intersections at 160 mm and 170 mm in height have been discarded, as they intersect the "shoulder" of the pot with a very low angle ( $\ll 5^\circ$ ), resulting in an intersection having a non-representative, random curvature.

Dividing ceramics into sections by characteristic points (like the "shoulder") is carried out by archaeologists for classification. Therefore we chose to analyze the object segmented into a lower and an upper part. This means, we have two fragments, where axis estimation can be applied, as for sherds (fragments). The estimation of the axis is shown in Figure 5(b,d). The numeric results for the axis are that they have a minimum distance of 4 mm towards each other and to the axis defined by the bottom plane. Furthermore the angles between the axes differ between  $5^\circ$  to  $7^\circ$ .

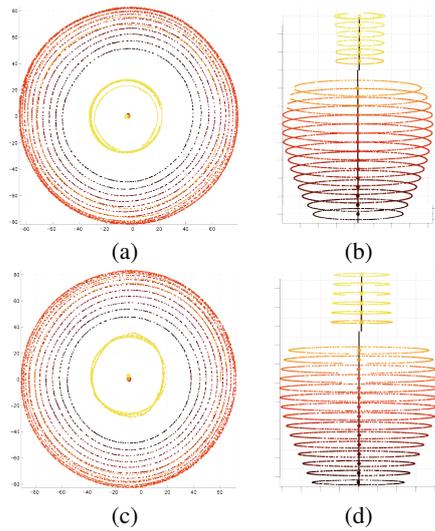


Figure 5: (a,c) Top-view and (b,d) side-view of the horizontal cross-sections - the level of gray corresponds to the height. The axis of rotation for the lower and upper part is shown as a black line, defined by the centers of the concentric circles (shown as dots).

Using the rotational axis of the lower and upper fragment, we repeated the estimation of the profile lines, which are shown in Figure 6. The maximum distance between the profile lines are 7 mm for the upper and 2 mm for the lower part. Therefore the first conclusion is that the upper and lower parts do have a different axis of rotation, which means that these parts have been produced separately and combined without the use of the rotational plate.

We can conclude that, based on the different deviation of the multiple profile lines shown in Figure 6, the upper part is of lesser quality than the lower part. This leads to the conclusion that these parts have been made by potters with different experience and/or on a slower rotational plate. Vice-versa the deviation in the upper part of up to 7 mm compared to less than 2 mm of the lower part, shows that a faster turning rotational plate has been used that more experience was required for manufacturing the upper part.

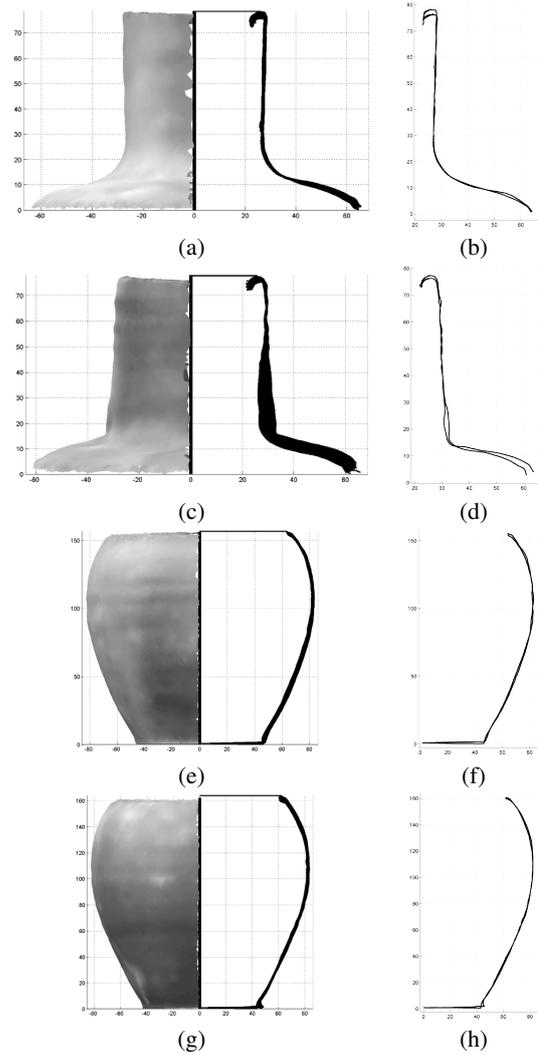


Figure 6: Axis of rotation and multiple profile lines of the upper part (a,e), lower part (c,g) and (b,d,f,h) the longest profile lines of the parts of the objects.

From the differing angle between the axis of rotation based on the bottom plane compared to the axis of rotation of the upper and lower fragment, we can conclude that either the bottom has been post-worked or the pot was contorted before being fired in the oven.

Even correcting the axis for the parts of the object, the horizontal intersections are not perfectly circular. The horizontal intersections are elliptic. Therefore we estimated the direction of the major and minor axis of the ellipses. We estimated that the minor axis has the same direction as the orientation of the handle. This means that the symmetry of the pots was broken, when the handle was attached and the pots were still wet. Figure 7 show the pots, intersected by a plane, defined by the center of gravity of the pot and the direction of the major axis of the ellipses. The angle between the minor axis and the handle of the pot was  $7^\circ$  and  $14^\circ$  for the second pot.

We additionally conclude that the ellipses fitted (Gander et al., 1994) to the horizontal cross-sections can be used as an additional feature. Therefore the distance between the foci of the ellipse is estimated. Ceramics with a distance converging towards zero (circular cross-sections) are of higher quality.

The proposed method has also been tested on 17 real vessels (Mara

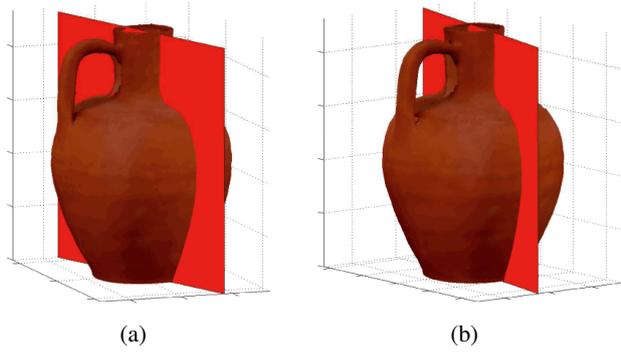


Figure 7: Planes of symmetry of the (a) first and (b) second object.

and Hecht, 2006), dated from the NASCA-period (Carmichael, 1986), which were found in the Valley of Palpa, Peru (Reindel and Cuadrado, 2001). Therefore we could separate these vessels into three classes determined by the symmetry. The vessels (60%) of two of these three classes were not produced on rotational plates. Beside this information – answer to the question of the manufacturing technique – about the use of rotational plates in South America, this classification is used by archaeologists of the German *Institute for Archaeology* (DAI, Bonn) for refinement of their classification schemes.

## 2.4 LINE DETECTION ON SURFACES

The approach shown in this section is an example to attempting to add the analysis of color information of ceramics, which already have been acquired for automated profile estimation as shown in the previous sections. The only requirement is to utilize a 3D-scanner capable of texture-mapping. The goal of this example is to apply image processing methods directly to this type of surface (texture mapped) images in order to analyze the drawings painted on surfaces of the pottery.

There are several approaches in the literature that deal with feature detection on surfaces. (Rössl et al., 2000) applies morphological operators to extract feature lines on triangulated surfaces. A similar approach was presented by (Pottmann et al., 2004) who apply morphological operators on surfaces, using new metric, called isophotic metric. While the main goal of these approaches is to discover characteristics in the curvature of the surface (e.g. defects on surfaces), we are interested in the texture, i.e. the pictorial information represented by the texture.

A method to enhance linear structures in 2D-images is the convolution of an image with an isotropic second derivative filter (LoG) (Marr and Hildreth, 1979). An isotropic filter has the advantage, that no directional information from the input data is necessary. On the other hand, no directional information is provided by the output. In our case, the adaptation for 3D-data is straight forward and is accomplished in two steps:

*Step 1: Definition of the "convolution window"* The image on the surface is given by a mesh of vertices  $v_i$  and each vertex is assigned a grey value  $g_i$ . For every vertex  $v_i$  a set of neighbored vertices  $b_i$ , i.e. the convolution window, is estimated. This is achieved by estimation of the distances along the surface (called geodesic distances) to direct neighbors of  $v_i$ . The set of vertices of the direct neighbors of  $v_i$  is called 1-ring. For 1-rings the geometric distance equals the geodesic distances. So, based on the geodesic distances of the 1-ring, the geodesic distances to  $v_i$  for all neighbors of the 1-ring can be approximated (Sun

and Abidi, 2001). This approximation is iteratively continued as "marching front" (Novotni and Klein, 2002) until no more vertices with a geodesic distance lower than  $dist$  are found. A schema of the geodesic distance is depicted in Figure 8(a). Figure 8(c) shows a detailed version of one randomly chosen vertex  $v_i$  and its geodesic neighborhood. The grey level in Figure 8 corresponds to the geometric distances, darker means lower geodesic distance.

*Step 2: The convolution:* The distance of a vertex  $v_i$  to  $b_i$  is denoted as  $d_{ij}$ . The 1D-filter kernel is defined as:

$$f(x) = \frac{1}{\sigma^2} \left( \frac{x^2}{\sigma^2} - 1 \right) e^{-\frac{x^2}{2\sigma^2}}$$

The discrete convolution is implemented as the sum of a component-wise multiplication of the grey values  $g_j$  assigned to all neighbored vertices  $b_i$  and  $v_i$  with the corresponding value of  $f(d_{ij})$ ,  $c_i = \sum_{j \in b_i, v_i} g_j f(d_{ij})$ .

The acquisition system provides two types of data, 3D-range data and 2D-images of the surface. Both data sets can be related to each other, e.g. each vertex of the 3D mesh can be assigned a color value and vice-versa. For our experiments we used the intensity value, i.e. the  $I$  component in the  $HSI$  color space, calculated from the color texture value. For the application of the derivative Gaussian filter we select all neighboring vertices with a geodesic distance less than  $1.5 \times$  the width of the expected line. This is an empirical value, which was obtained from our experiments with 2D-line images, where the size of the filter kernel had to be 3 times the width of the lines. Figure 8 shows the comparison between (c) the manual drawing, (d) the automated unwrapping (do Carmo, 1976, Strubecker, 1969) of the texture-map of the 3D-model and (e) the detected lines highlighted in black. Regarding performance this experiment shows that the automated estimation of a drawing similar to the manual drawing can be obtained within seconds instead of hours. Future work will add pattern recognition methods (e.g. shape-matching) to obtain missing parts of the paintings and to automatically find similar decorations within a collection of 3D-models.

## 3 COINS

As we do not want to limit our system to ceramics, we recently started research for integrating the documentation of ancient coins, another common find, which is typically acquired by digital cameras. Besides automated coin recognition and classification based on 2D-images, we also want to acquire 3D-data, because medieval coins are not as flat as their modern counterparts. This would lead to new perspectives of studying ancient coins as well as new strategies for representing them. Based on the images of coins for documentation purposes, we propose a pattern recognition system for automatic estimation of an abstract description and for determination of the type an ancient coin belongs to. While this can be done quite quickly by an expert, we were asked by them to apply this system on images found on the web using web-crawling techniques, because coins are often stolen from excavations and sold on the black market using the internet.

Recent research approaches for coin classification algorithms focus solely on the recognition of modern coins. Applied pattern recognition algorithms are manifold ranging from neural networks (M.Fukumi et al., 1992, Bremananth et al., 2005) to eigenspaces (Huber et al., 2005), decision trees (Davidsson, 1996), edge detection and gradient directions (Nölle et al., 2003, Reisert et al.,

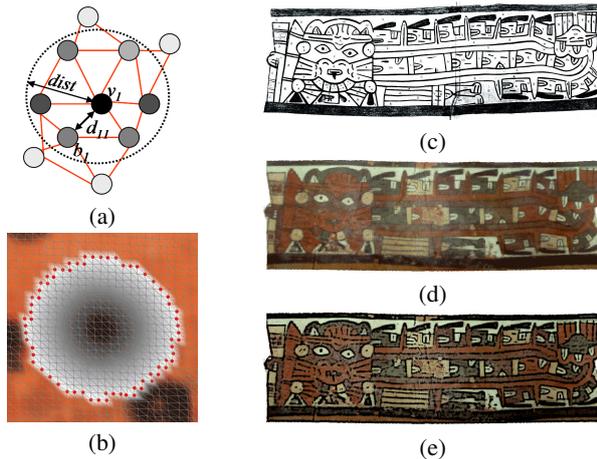


Figure 8: (a) Graphic illustrating the active vertex  $v_1$  (black) and the neighbored vertices  $b_1$  within the geodesic distance  $dist$ . (b) Detailed sample of a randomly selected vertex  $v$  and its geodesic neighborhood. The level of grey corresponds to the geodesic distance - darker means closer. Unwrapping of the decoration of vessel 2801-V3 of the excavation in the Valley of Palpa, Peru: (c) manual drawing, (d) unwrapped texture and (e) texture with detected edges (highlighted in black).

2006), and contour and texture features (van der Maaten and Postma, 2006). (Huber et al., 2005) presents a multistage classifier based on eigenspaces that is able to discriminate between hundreds of coin classes. Due to the controlled setup of the system presented coin detection becomes a trivial task. They report correct classification for 92.23% of all 11,949 coins in a sample set. (van der Maaten and Poon, 2006) presents a coin classification system based on edge-based statistical features, called *COIN-O-MATIC*. The system is subdivided into five stages: segmentation, feature extraction, preselection, 3- nearest neighbor approach, and verification. At the *MUSCLE CIS Coin Competition* (Nölle et al., 2006) the method achieved a recognition rate of 67.31% on a benchmark set of 10,000 coins. The coin classification method proposed by (Reisert et al., 2006) is based on gradient information. Similar to the work of (Nölle et al., 2003) coins are classified by registering and comparing the coin with a preselected subset of all reference coins. The proposed method won the *MUSCLE CIS Coin Competition 2006* (Nölle et al., 2006) with a recognition rate of 97.24% on a benchmark set of 10,000 coins.

Tests performed on image collections both of medieval and modern coins show that algorithms performing well on modern coins do not necessarily meet the requirements for classification of medieval ones (van der Maaten and Postma, 2006). The main difference between ancient and modern coins is that the ancient coins have no rotational symmetry and consequently their diameter is unknown. Since ancient coins are all too often in very poor conditions, common recognition algorithms can easily fail. The features that most influence the quality of the recognition process are yet unexplored. An example of an ancient coin from a dataset consisting of 3,000 high resolution images of ancient coins on constant, white background is shown in Figure 9<sup>2</sup>. The coins picture Roman emperors from  $\approx 30$  B.C. to  $\approx 300$  A.D. who form the 106 classes of the dataset.

In the first stage of our recently initiated research, we started by analyzing and evaluating the existing algorithms for coin recogni-

<sup>2</sup>The data set was made available by Klaus Vondrovec, Numismatic Commission, Vienna, Austria



Figure 9: Example images of the ancient data set.<sup>1</sup>

tion. Initial tests were performed using a *MUSCLE CIS* database of coins consisting of over 9,100 training images (distributed over 100 classes of coins) and 1,100 test images. We applied the algorithm provided by Maaten (van der Maaten and Postma, 2006) based on edge-based statistical distributions. Unlike Maaten, we completely ignored sensor measures (such as thickness or diameter) and thus we only rely on the extracted features. Our experiments based on the multi-scale edge angle-distance distribution achieved a recognition rate of 63%. Surprisingly, coin classification based solely on area measurement achieved a rate of 45%. Ancient coins differ strongly from modern ones. Crucial influence has the nature of the medieval coins, which are less details, no rotational symmetry and poor conditions due to abrasion or fouling. Hence, coin classification based solely on edge-based features would most probably fail with the classification of ancient coins. In the next stage, we will perform tests on a medieval database to find those features (or set of features) that most influence the quality of medieval coin representations.

#### 4 SUMMARY AND OUTLOOK

Summarizing the present work shows how our heritage can be retrieved, when it has been lost or stolen and how it can be preserved using digital documentation using 3D- and 2D-image processing and pattern recognition methods. Furthermore these automated methods help experts of cultural heritage to dramatically reduce time for documentation of the majority of finds within archaeology and to reduce the time to search numismatic databases containing thousands of coins.

Beside improvement of existing methods for 3D-Vision another important work has recently begun to ensure the intellectual integrity, reliability, transparency, documentation, standards, sustainability and accessibility of the information gathered by the increasing use of 3D-scanners. Therefore we are adopting *The London Charter* (Beacham et al., 2006), which will be a future standard for the use of 3D-Vision within Cultural Heritage.

For future work we will combine the methodologies for coins and ceramics to achieve a more generic system to retrieve stolen ceramics and to document and manage coins within digital libraries. Furthermore the methods used to retrieve stolen finds will also be used to reveal new knowledge hidden within the tremendous amounts of finds using features of their surfaces.

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