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Acquisition and Visualization of Cross Section Surface Characteristics for Identification of Archaeological Ceramics

Abstract: We describe a new system for digitizing ceramic fabric reference collections and a preliminary evaluation of its applicability to archaeological ceramics identification. An important feature in the analysis of ceramic fabrics is the surface texture of the fresh cross section. Visibility of surface characteristics and fabric constituents on images strongly improves with the ability to rotate a sample or vary the angle of illumination. Interactive online catalogues, showing these variations using sequences of images, offer the means to imitate visual examination of the real sample. Accordingly, we have developed a system for automatic acquisition of image sequences and software to display and interact with the sequences on the web. Our system improves the visualization of the fabric characteristics to a substantial degree and may encourage the scientific use of online image reference collections. Furthermore, this system is applicable to other material categories where visual surface characteristics are important for identification.

Introduction

In archaeology, pottery is traditionally associated with typological studies. In recent years, ceramic scientists as well as archaeologists have supported the analysis of the material constituents of large quantities of ceramics. This research is known as fabric analysis. Fabrics research assists the archaeologist in the interpretation of the ceramics retrieved during field work. Another objective of fabrics research is the reconstruction of the pottery industry in the past. The methods employed include detailed visual examination using simple scientific techniques such as thin-sectioning and the assessment of colour and particle-size. These methods are suitable for studying large quantities of ceramics.

Between 1977 and 2001, the Groningen Institute of Archaeology (GIA) conducted stratigraphical excavations at the ancient settlement named Satricum, present-day Borgo Le Ferriere in South Lazio, 60 km SW of Rome (Italy). This archaeological project examined areas of the settlement, a necropolis and a votive deposit on the acropolis, near the remains of a temple (Maaskant-Kleibrink 1987, 1992; Attema 2003). Simultaneously, from the mid-1980s onwards, another extensive GIA project focused on the development of settlements in the province of Lazio between the 9th and 3rd century BC. This project involved surveys on ploughed arable land. Building structures were measured and surface finds such as lithics, ceramic sherds and metal objects were collected and assessed (Attema 1993).

Both projects produced large quantities of ceramic sherds. Although the majority of ceramics from Satricum were fragmented and damaged, detailed information could still be retrieved to produce pottery typologies and dates. The survey material appeared to be more problematic. Due to repeated ploughing and weathering, most of the survey ceramics were damaged to a high extent. The lack of typological information complicated the interpretation and dating.

Fabric analysis offered a tool for comparing the stratigraphically embedded material from Satricum to the geographically scattered finds from the surveys. Thousands of sherds dated to the period 900–300 BC have been subjected to fabric analysis during various campaigns. These sherds were classified according to their material characteristics, each described with a fabric code. On the basis of general developments in pottery technology, as observed for the ceramics of Satricum, a substantial part of the survey sherds could be assigned to specific periods (www.lcm.rug.nl, under Research: fabric analysis on ceramics from Lazio, Italy).

Physical reference collections are crucial for fabrics research. During fieldwork, a small reference collection is often used. A strong selection, however, does not cover the variety of characteristics present in most fabrics. Furthermore, the physical collection is not open to other researchers working in Latial archaeology. A web-based digital image reference collection would be ideal to solve some of the drawbacks mentioned. It can broaden or

replace a small physical field reference collection, and it offers other researchers the means to use the collected data and knowledge. In this way we adhere to the idea of a "National Reference Collection" (Lange 2004).

A digital image collection should imitate as far as possible the circumstances under which ceramics are being studied. Single images are unsuitable, even if the level of detail approaches the usual magnification of 5 to 30 times. Single images lack information on the surface structure (bumps and dents) and the reflection properties of the fired clay and its constituents. A fabric expert will always rotate the sample to observe all aspects of the material. Therefore, digitizing this rotation is the most promising approach for building a digital online fabrics reference collection.

Rotation of the sample helps in partially overcoming the lack in realism observed when viewing a 2D image of the sample. Due to "the loss of dimension", 2D images of 3D objects suffer from ambiguities, for example the bas-relief ambiguity (Belhumeur / Kriegman / Yuille 1999). This results in perceptual interactions between roughness/shape, illumination and material perception (Ho / Landy / Maloney 2006; te Pas / Pont 2005). The fact that object surfaces look different when viewed or illuminated from different angles is subject of study in computer vision and computer graphics research. The appearance of surface texture as a function of viewing and illumination direction is represented by the Bidirectional Texture Function (BTF) (Dana et al. 1997). Research on finding methods to measure and model the BTF and related functions has lead to techniques for more realistic rendering of 3D scenes. Another approach to photo-realistic rendering is the use of "reference" images instead of a geometric model of the 3D scene. Some of these image-based rendering techniques have been successfully applied to the cultural heritage domain (Dellepiane et al. 2006; Mudge et al. 2006). A more direct approach to realistic visualisation of object surface properties on the web is using an "object movie"; a method supported by QuickTime VR technology (Chen 1995). This technique uses image sequences that show object rotation to create virtual representations of those objects. We use a similar technique, but we have optimised it for ceramic fabric analysis. Compared to other techniques like those using 3D scanning, this is relatively easy, quick and inexpensive. These are important properties, because we are not interested in digitizing just a few objects, but rather whole collections, each spanning hundreds or even thousands of objects. Another criterion for the system is that fabric experts should be able to digitise their collection without depending on help from computer experts.

Acquisition of Image Sequences

Setup

The acquisition setup mimics the configuration used by fabrics experts when examining fabrics samples. Fabrics experts orient the surface of the fracture towards them by holding it horizontally between thumb and fingers of both hands. Then, by movement of fingers and wrists, the sample is turned (tilted) in such way that the light from above illuminates the fabric in a way that exposes most of its properties *(Fig. 1a)*. When a binocular microscope is used the setup is similar, with the observer looking into the microscope while holding the sample underneath it.

Instead of tilting the sample (rotation around a horizontal axis), we use a configuration with a rotational stage. The sample is standing on this stage and rotates around a vertical axis, along the line of gravity. This is accomplished by turning the whole scene 90 degrees to one side as seen from the viewpoint of the camera. The light will then come from one side instead of from above *(Fig. 1b)*. The camera could be turned around its optical axis as well; changing from 'landscape' to 'portrait' mode, but the same effect is accomplished digitally.

The sample is illuminated using a regular photo studio light source which is placed at a distance of 1–2 m from the sample, and with an angle in the range of 30–60° between camera and light source with respect to the object. The angle between the optical axis of the camera and the surface normal of the fracture will be about 30°. The acquisition session starts with an orientation of the sample that lets the light have an inclination of about 10° with the fracture surface, casting shadow thereby revealing the surface structure (Pont / Koenderink 2005). Then, the table is rotated (~30°) in the direction that makes the camera point straight at the fracture surface (frontal viewing). The rotation is continued for about 60°, resulting in a total rotation angle of about 90° *(Fig. 1c)*.

Positioning and orienting the sample on the rotation stage is a precise task. The aim is to keep the

fracture surface from moving outside the field of view as much as possible while the sample is being rotated. This is partly accomplished by having the centreline of the fracture surface coincide with the rotational axis. This centre will then keep its position, but one of the surface borders will now move towards the camera and the other will move away from the camera when the sample is rotated. In order to get most of the surface in focus, the depth of field should be maximised by selecting a narrow aperture (high f-number). This also helps to counteract the effect of partially unfocussed images due to the surface irregularity and imperfect positioning of the sample.

The camera being used should support a macro photography setting (close-up). This allows the camera to focus on nearby objects and capture the small details needed for fabric research. Consequently, the system is sensitive to movement artefacts caused by touching the camera. Therefore it is best to release the camera shutter by remote control.

Hardware and Software

Because we are adapting the system to the specific needs of archaeologists, we decided to build our own image acquisition system. We are aiming for a system that can be used by an archaeologist without the need to consult computer experts. Therefore, we choose to build the system to work with a commonly used computer system, a standard office PC running a widely used operating system (Microsoft Windows 2000, XP). In this way the acquisition can be done using a standard computer, cutting costs and learning time for operating the software.

The acquisition program was developed using the de facto industrial standard (Microsoft Visual C++) for developing this type of application and, as a result, it was easy to obtain the software libraries we needed for controlling the hardware. The acquisition software needs to control both the object rotation and a digital camera. Camera control is accomplished by using the software development kit (SDK) supplied by the manufacturer of the camera.
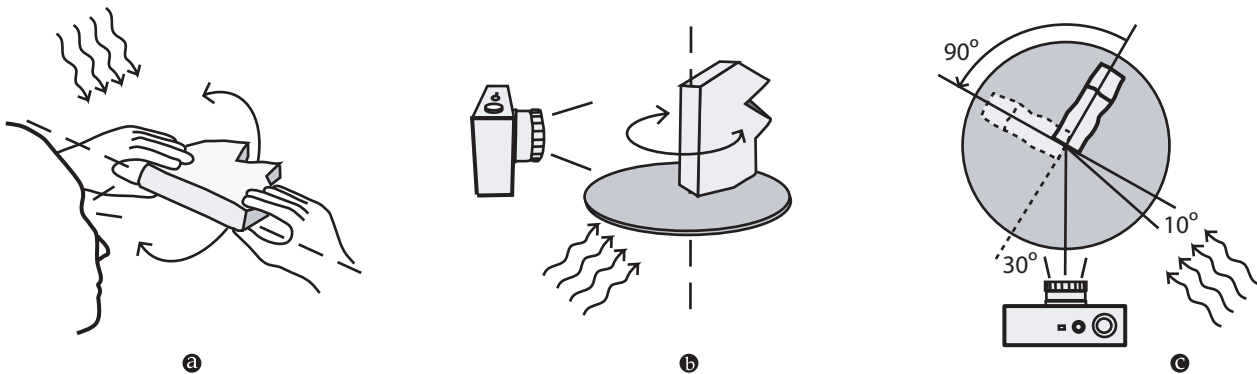

Fig. 1. Mimicking the examination of a fabrics expert. a) Tilting and examining the sample. b) Rotating the sample on a table. c) Table rotation; seen from above.

An image sequence is captured by rotating the stage with the object using angular changes of a fixed size and after every change an image is acquired. The choice of the angle and thereby the total number of images, is a trade-off. A smaller angle results in a more fluent movement in the movie but also in more data that needs to be downloaded and processed, both during acquisition and presentation.

The image sequences can also be acquired by manually rotating a graded stage and releasing the camera shutter by hand. But an automated (computer controlled) procedure is preferable for digitizing large collections, because it is faster, more accurate and less error prone.

With the camera connected to the PC, the software can change camera settings like shutter speed and aperture and also release the shutter and acquire the resulting image data. Because we have a compact camera with remote control options available, we use the SDK from that manufacturer (Canon), and as a result our system currently only works with these cameras, but we plan to support other cameras as well. The acquisition software has the option of acquiring images with a camera that does not support remote control and image acquisition. In this case, after a rotation, the application notifies the acquisition operator when a picture has to be taken and then waits for the operator to continue the acquisition session.
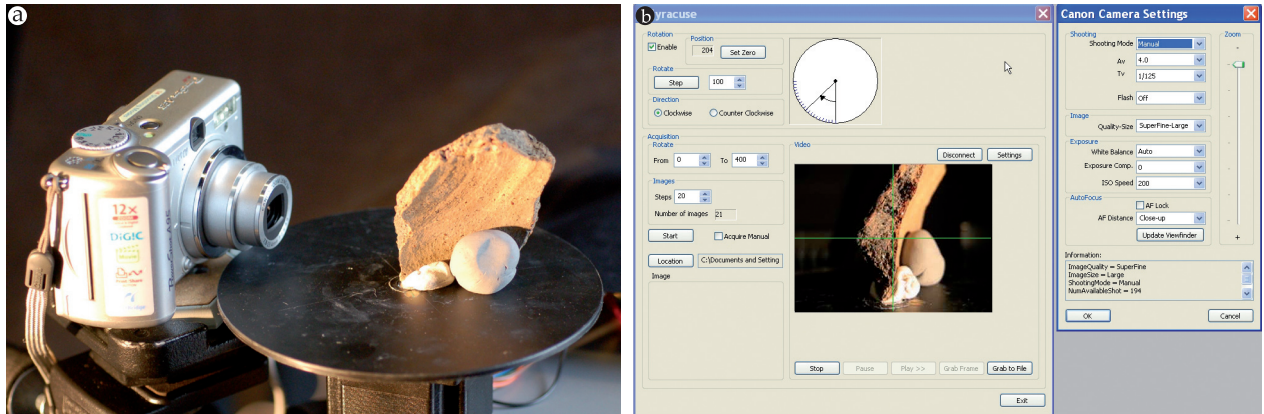
Fig. 2. Acquisition of a sequence or "object movie". a) Rotation of a sample. b) Screenshot showing the application windows for acquisition and camera settings.

For computer-controlled object rotation, we used a stepper motor and accompanying micro step driver obtained from a company providing computer controlled machine tools (www.stappenmotor.nl). Both driver (type: MSD-32-2.5) and motor (type: 23SM056-028-8W-F10-1.3) can be powered by the PC's power supply unit. Stepper motors have the property of rotating with almost discrete steps, causing vibrations to the sample attached to the rotation axis. Smaller steps make these vibrations less problematic and therefore the option to rotate with 'micro steps' was essential for our purpose. The driver was connected to the PC's parallel port and for the communication with the acquisition software we used a free software library (inpout32.dll available at www.logix4u.net).

The acquisition session setup is depicted by *Fig. 2a.* The camera, light and sample are placed as described in the previous section and the application is used to acquire the images. When the application is started and the connection with the camera established, the "live" camera viewfinder image can be displayed. This is useful for adjusting the camera settings, camera position and orientation. The acquisition session parameters can be set when the camera views on the object have been inspected for focus and illumination under different rotation angles. These session parameters are: number of steps between each release of the camera shutter (taking a picture) and the positions for starting and ending the acquisition.

Experiments

To optimise the system for fabric analysis, we acquired image sequences of nine test samples and did an informal pilot evaluation of their value for fabric determination. The fabrics expert selected three fabrics and of each fabric three samples, so as to have a representation of the variation within a type. Two of the fabric types were closely related and had similar characteristics, thereby posing the challenge of distinguishing them from each other, and the third was very different. To expose the fabric characteristics, fresh fractures where made for each sample. The samples were then handed over to a non-expert who randomly ordered and numbered them.

For the image acquisition, we used the setup as described in the section "Setup", with a 1000 W halogen photo studio light at approximately 1.5 m distance from the object. For each sequence, 60 images where acquired 1.8 degrees apart. A digital compact camera manufactured by Canon (type: Powershot A95) was used with the following settings for all images: exposure time $1/125$s, f number $f/4$, ISA 200, superfine, high quality JPG, size: 2592 x 1944.

After the acquisition, the images were rotated 90 degrees anticlockwise. Images of that size would be problematic to present as a sequence on the internet and therefore we decided, after inspection of the images, to digitally cut out sub-images of 1100 x 900 pixels, still showing most features of the fabric. The sub-images were further reduced in size by scaling them by 50%, resulting in a final image size of 550 x 450 pixels. These images were placed on the internet and the sequences examined using interactive viewing software (a Java Applet) embedded in the webpage. We developed this viewing software which allows an observer to rotate the object by dragging with the mouse, adding to the suggestion of reality. Screenshots of the resulting web pages are shown in *Fig. 3*.
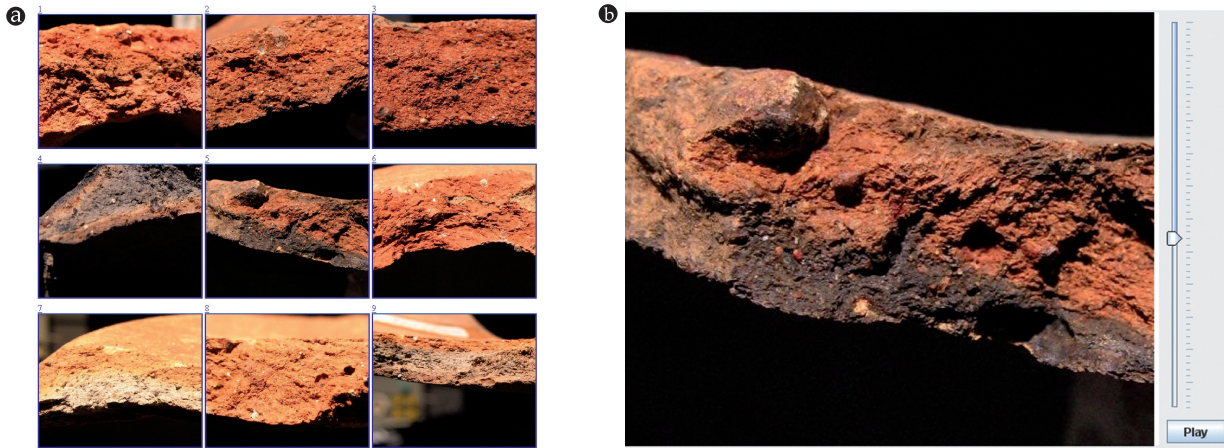
The first test was to determine if the expert could

Fig. 3. Screenshots of web pages used for the experiments. a) Nine samples from three different fabrics. b) Sequence viewer with the 5th (central) sample.
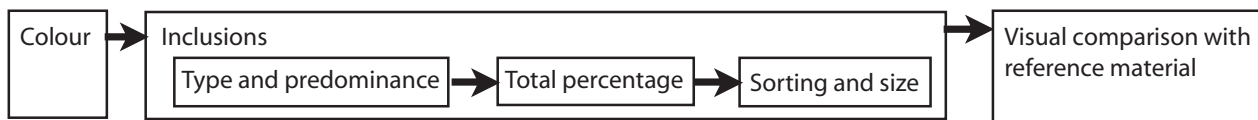

Fig. 4. The fabric classification process.

identify the fabric type correctly, using the digital images instead of the real samples. This test was performed in two stages. In the first stage, only a single image from each sequence was used for inspection. This was the image from the middle of the sequence, after about 45 degrees rotation of the sample. When this inspection was completed for each sample, the second stage was to use the image sequences with the interactive viewing software. The digital samples were examined using a PC with a 17" monitor at a resolution of 1280 x 1024 pixels which displayed the webpage with the images. When using both single images and sequences, the expert could correctly classify six of the nine samples, based on the visible characteristics only.

The second pilot experiment was more realistic, in that it tried to mimic the use of a reference collection; identifying an unknown sample. A set of 15 fabric samples from the reference collection was compared with the nine digital samples. For each fabric sample, the observer had to select the most similar digital sample or decide that none was similar. It was not known to the observer how many of the 15 samples where similar to the three fabrics. In contrast to the first test, the examination and comparison was now done by a non-expert who was unaware of the types in the fabric collection. Before the actual comparison with the digital online fabrics took place, the 15 sherds where carefully examined under guidance of the expert. These lessons where essential for the non-expert to understand which details had to be ignored and which details were important. This made the test more realistic, because a fabric collection would not likely be used by someone completely unaware of fabric characteristics. During these lessons in fabric analysis, the non-expert tried to ascertain the important characteristics of each sample and used those to determine the fabric type.

The examination of the real samples was done with a binocular microscope, using the procedure for fabrics classification as described by Attema (Attema et al. 2003 or www.lcm.rug.nl). In short, this involved determining type, percentage and size distribution of inclusions and the colour of the clay. The different steps of the classification process are depicted in *Fig. 4*. Finally the samples were compared with the digital images as before, firstly with single images and then using the complete sequences with the interactive viewing software. Using the sequences, nine of the fifteen samples were correctly classified and with the single images twelve.

Discussion, Conclusions and Future Work

The experiments revealed that the image sequences gave a good overall impression of the fabric. Inclusions with highly reflective, crystalline surfaces became prominent when using the image sequences, caused by glistening effects at specular angles. Futhermore, surface roughness was exposed by the

images from the sequence with a shallow illumination angle. However, this "realism" did not result in an improvement of the fabric identification during the tests. The images did not show enough detail to determine all types of inclusions and their percentages. In some cases, overexposure and defocus also reduced the usability of the images. When the sequences showed part of the inside or outside of the sample (potsherd), this was helpful for identification of the pottery type, but this can not be used for strict fabric analysis.

The experiments we performed with the test images were simple pilot tests for evaluation of the system's applicability to fabric analysis. They were not adequate to determine to what extent the "extra" information contained in the image sequences can be used for discriminating surface texture and roughness. In future research, we will systematically evaluate the value of the dynamical representations as a function of viewing and illumination ranges, using formal psychophysical methods and parameterised image sets.

Because the quality and detail of the test images was not adequate to be applied to fabric determination, both image acquisition and presentation need to be improved. Care must be taken to avoid overexposure and defocus. The latter can be avoided by using an optical system with better depth of field. Finally, the presentation software should support larger images, thereby showing more detail of the fabric. Larger images can also describe a larger area of the fracture surface, better revealing the local variations of the fabric characteristics within a sample.

Eventually, the image sequences will be available in an online fabrics reference collection. This online reference collection will present the information in a structured way, showing commonalities and variety within a fabric and between fabrics. Together with textual descriptions and drawings, it would be useful to display the inside and outside of samples. The realism added by the image sequences probably makes a digital reference collection more acceptable to archaeologists and will result in a growing use of the collection.

When a digital fabrics reference collection is realised, it will be desirable to develop computerised means for identification of fabrics using their characteristic bidirectional surface reflectance and texture properties. In a related research project, we are developing content based image retrieval techniques for identifying archaeological objects

(van der Maaten et al. in press). These techniques do not yet use image sequences to classify the object texture, but adding sequences might improve the performance. The observed texture changes as a function of the angle of view and the angle of illumination due to effects of shading, shadowing, occlusions and interreflections. Possibly these effects could be used as unique (identifying) characteristics for an automatic classification or determination system (Cula / Dana 2004; Chantler et al. 2005). The challenge would be to have the computer successfully use the information contained in the image sequences without having the full BTF. Machine learning, image processing and computer vision techniques could be used to realise such a system.

Acknowledgements

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