Topometrical measurements in Tiryns, Greece
Report on a co-operate project between physics and archaeology

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Abstract: The cooperation between archaeologists from Heidelberg and physicists from M•nster started in 1999 in order to develop an application based on optical systems of phase measuring profilometry for non contact acquisition of 3D coordinates from objects of various sizes. 3D coordinates are stored in file formats that can be processed for 3D mapping, interactive 3D analysis, video output and two dimensional documentation.

Already existing devices had to be adapted to transportation and to the situation on site and in the museum. A modular software with parallel and automized data processing as well as automatic matching of point clouds from single measurements with special reference cubes was developed. Due to automation, the measuring process became quicker and flawless, and the amount of data to be stored was reduced dramatically. The modular software design is open to additional, independent features.

This paper presents the steps of development and three examples of different scale: A small find, a burial during excavation and a large stair case from the site of Tiryns.

Key words: phase measuring profilometry, photogrammetry, 3D, fringe projection technique, digital image processing, Tiryns, small finds, architectural remains

Project outline

The Laboratory for Biophysics in the department of medicine at the university of Münster is focused on research in optics and has a tradition in cooperation with social sciences (e.g. Dirksen et al., 2000.; Dirksen, von Bally, Bollmann, 2000). A few years ago cooperation with archaeological institutions began, and in 1999 the archaeological institute (Ur- und Frühgeschichte) at the university of Heidelberg joined a project to create a portable system for non-contact 3D measurement of archaeological finds and sites of various sizes on the basis of photogrammetry (Böröcz et al., 1999, Böröcz et al., 2000). Münster already had some experience with a similar, non-portable system that had previously been developed for medical applications.[1]

The task of the archaeologists was to check the developments in Münster for their archaeological relevance, organize test measurements of sites during excavation and of archaeological remains and small finds. They had to take part in the test measurements to evaluate the applicability for archaeologists. Test measurements took place in two campaigns in Tiryns, Greece. Tiryns is a site in the Argos plain near Nafplion. Although it bears remains from many archaeological periods, it is best known for its Bronze Age remains on a hill rock and in the surrounding plain which are of great importance in the Aegean world beside those in Mycenae, Pylos and Theben. Tiryns had been excavated in several campaigns between 1884 - 1888 by H. Schliemann and W. Dörpfeld, between 1905 and 1929 by W. Dörpfeld, K. Müller and G. Karo, and by K. Kilian between 1976 and 1985 and it has been on the UNESCO World Cultural Heritage List since 1999. Since 1994 new excavations of the Institut für Ur- und Frühgeschichte, Heidelberg on behalf of the German Archaeological Insitute in cooperation with the Fourth Ephorate of the Greek Antiquity Service are going on in the lower citadel (Unterburg) and the northeastern lower town (Maran 2000). The project team could carry out measurements of the cyclopic walls, of architectural remains, of the excavation site and of small finds in the storehouse.

In spring 1999 the team worked on portability and outdoor applicability of the system and focussed on basic archaeological problems. The system should be stable rather than elegant or fast in this project phase. It was tested on site during the excavation campaign in Tiryns in summer 1999. Analysis of the experiences from the test phase lead to a new design of many modules - hardware, software and additional instruments. In the following year until the next excavation campaign, the team tried to realize at least part of the ideas. These were tested successfully in summer 2000, which means that only slight changes to the ideas from 1999 have to be implemented now, development can go on as designed in autumn 1999.

Technical Background

Physics

The basis of the system is a topometric sensorhead consisting of two CCD cameras, and a fringe projector in the centre. During the measuring process a sequence of phase shifted quasi-sinusoidal fringes from a slide made of metal coated glass substrate is projected onto the object and registered as stereo images by the CCD cameras. After calculating the phase distribution from the digitized images, the stereoscopic images are evaluated by photogrammetric techniques, and a 3D coordinate is calculated for each valid pixel. The achievable measurement accuracy depends on the triangulation angle (the angle between the cameras), the image field size, as well as on the number of camera pixels. With a triangulation angle of 40 degrees and an image diagonal of approximately 20 cm for small finds for example, the height resolution is situated at less than 50 micrometers, the lateral at approximately 200 micrometers.

Using the obtained coordinate points - the point cloud - the object surface is reconstructed by triangulation, that is by covering it with a grid of triangles. As the investigated objects are quite complex, an approach is used which does not make special assumptions about the surface structure, it iteratively connects neighbouring points, only controlled by preset angular and distance constraints. It allows automatic processing - including the computation of range images - of large numbers of samples and single measurements (Dirksen, Kozlov, von Bally 1997, Dirksen et al. 2000).

To match sample point clouds from different angles into one 3D model, at least three identical reference points have to be identified in the first point cloud as well as in the second. These reference points can be part of the object itself or can be added into the object artificially before measuring. Artificial reference points can be designed for automatic identification by the software.

Outline of the measurement procedure

At the beginning of each measurement process, the camera lenses and their triangulation angle are chosen according to the size of the object and the measurement accuracy to be achieved. Cameras and slide projector are positioned on the sensorhead and calibrated before the measuring session starts (fig. 1).

For measuring, the slide projector throws patterns of light and shadow on the object (fig.3). The use of white light projection requires darkness or at least a subdued background illumination in order not to distort the projection. In a museum this is usually no problem, on site, however, measurements have to be made during night or with e.g. a tent. Fig. 2 shows the adjustment of lightning before projecting the fringe pattern that are recorded by the two video cameras. Colours in the false colour image inform about best lighting conditions. In some cases, measurements have to be done twice because the CCD cameras lack a sufficient dynamic range.

After acquiring the 3D coordinates, the reference points have to be identified. If artificial reference points are used, they have to be deleted from the point cloud since they do not refer to the real object. The next measurement can take place, it has to include the reference points of the previous measurement to be adjusted to the next point cloud (fig. 4).

To check the results, all point clouds can be matched from time to time and evaluated in a viewer on the computer screen (fig. 5) or by the software.

Many of these steps can be automized, which was one of the main tasks of the developing team. They shall be introduced later.

Hardware equipment

The project started with this hardware equipment: The main processor was a Pentium II with 266 MHz and 256 MB of RAM storage (PS/2 EDO-RAM), had 10 and 4 Gigabyte hard discs. After each measurement session, backup CDs had to be burnt. Different camera lenses are used for objects of different size, focal length used on site most often is 6mm, for small finds 12 mm, rarely 25 mm, all Pentax/Cosmica. The camera is XC-75CE from Sony, with one colour channel of 8 bit depth and a solution of 768 by 572 pixels.

The basic measurement software that runs the projecting device and cameras (ATOS, Advanced Topometric Sensor) was provided by the company GOM, Braunschweig, Germany. The software was partly replaced by new modules developed in the course of the project (OSCAN Toolbox, Object Scanner Toolbox). Both work with Linux as Operating System.

In the first measurement compaign the computer equipment was completely busy during repositioning of the sensorhead. The developement of OSCAN provided automation of time-consuming manual parts of the original measurement process. Therefore in the second campaign the attended time for computing the 3D-information for each measurement was greater than the time for repositioning the sensorhead. Implementation of new computer hardware will increase the measurement process by a factor of 3 and more, depending on the find.

Reference points, reference tables and reference cubes

The project started with reference points that were individually attached to the object. They had to be identified by mouse clicks and named in a dialogue box. For calculating the 3D coordinates of the object itself, the area of these additional points had to be cut out before calculating the point cloud. For automatic identification and naming of reference points, reference tables were developed, which worked reliably already during the first test phase. For the next test phase, these were further improved to reference cubes (fig. 6).

Advantages of the cube are manyfold: Instead of placing several refence tables facing to different directions, it only needs one cube in a certain area because the software already knows the identity of reference points and the 3D coordinates on all sides of the cube. The design allows the automation of several steps during the measurement.

The three circles form the reference points. The binary code differs on each side of the cube and on each cube, the software can identify the reference points automatically. The size of the cube differs according to the size of the measurement area. Sometimes, it is necessary to measure an interesting spot more detailed. For this case, the small pattern can serve as reference points.

The cubes can be dismantled, so they need to be calibrated before usage, another part of the OSCAN toolbox. Small cubes for small finds were very stable, they are not dismantled and can be used without calibration for several weeks and even after long transports. The reference cubes are filed to patent by the German Patent Office Munich, AZ 100 50 892.8 1 2.

Simplification of the measurement process

Fig. 7 shows the steps of measurement between calibration of the cameras and storing the data. The steps displayed in the light grey area refer to the object or take place in the site itself, those in the dark grey area are steps of control on the computer screen. The most important improvement in the light grey area are the reference cubes, the most important improvement in the dark grey area is automation. It increases measurement speed by a factor of 4 to 5, not to mention handling errors that can be avoided.

In addition to automation, improvements in the dark grey area of the diagram refer to data management. The original system stored every acquired coordinate point for each single measurement. It was impossible during the measurement session to check the overlap between single measurements, thus, many coordinate points were stored more than once. From time to time, the measurement process was interrupted to check the point cloud in a viewer. OSCAN now calculates the overlap and deletes coordinates which are stored more than once after each measurement automatically without using the viewer. The user is always informed whether there is too much overlap, so the sensorhead can be focused on a new part of the object instead of repeating measurement of the same part from a different angle. Reduction of data by avoiding redundant measurements and by deleting reduntant coordinate points is another achievement of OSCAN.

The preceptions from the campaign in the year 2000 lead to a new graphic user interface for a more friendly use with additional functions for documentation of the measurement and analysis. Thanks to the modular software design, additional modules can be developed without detailed knowledge of the internal software structures.

Fig. 8 shows two examples of the new user interface. OSCAN can handle several objects measurings at the same time. Each object is stored in a file structure as a "project", the four most important projects can be accessed immediately with the button on the control dialogue box. The dialogue box in fig. 8b has to be checked after each single measurement: As soon as the software has identified the reference points, the numbers are shown on the screen in order to check them. With a click on the button "accept" the next steps go on automatically as shown in fig. 7.

Samples of application

Figs. 9, 10, 11 show examples of measurements of objects with different size, table 1 compares effectiveness and speed of measurement. Fig. 9 shows a small find from Tiryns. Cross sections can substitute drawings; cross cuts from cuneiform tables, seals or cast objects are particularly interesting for archaeological analysis, since they show details in the range of several micrometers. Measurement of this sample took place in the second campaign with a reference cube.

Fig. 10 shows a burial from the lower town. Measurement took place during the second campaign, but since reference cubes could not be positioned in the steep enclosure, reference tables were used instead. Their design was improved exactly like that of the reference cubes, so the whole measurement process was automized.

Fig. 11 shows a staircase from the citadel (Mittelburg) that was measured in the first campaign. With a length of more than 8 m it is an extraordinarily large object.

Each measurement session took place under different conditions. Table 1 shows, how much the improvements between first and second campaign served a quick and efficient measurement: For the burial, almost all of the acquired coordinate points were used, whereas for the staircase in the first year measurement almost two thirds of the acquired points were still reduntant. The table presents the original measurement time for the staircase and a time estimation calculated from the parameters of the automized procedure of the second year. With the new hardware equipment, the measuring time can be further improved. The effectiveness for small finds seems to be low on first sight, but the object covered only about 10% of the area the cameas could capture. The redundancy of coordinate points on the object itself was only about 10%, which is even better than the results from the burial.

Discussion

Non contact acquisition of 3D coordinates on the basis of photogrammetry is a well established technique and already employed for documentation of archaeological finds. This project developed a high-precision and easy-to-use system that cannot only be applied to smaller objects, but also in the field of excavation, to scan sites and large objects like walls and other architectural remains. The robust equipment can be transported and used anywhere. The results are as accurate as those of established indoor solutions for smaller objects. 3D data of this kind are inevitable for VR-site documentation that may play a more important role in future archaeological publications, but as well for better methods of analysis. Further modules for presentation, documentation and analyses can be developed as additional modules (add-ins) to OSCAN.

End notes

This and similar techniques are being applied in several interdisciplinary projects concerning archaeology and related fields, some of them have been introduced in this and preceding CAA conferences. More projects and literature are introduced in the Internet, this is an arbitrary selection:
http://www.brunel.ac.uk/project/murale/home.html
http://www.prip.tuwien.ac.at/Research/ArcheologicalSherds/lit.html
http://www.research.ibm.com/pieta/index.htm
http://www.research.ibm.com/pieta/pieta_refs.htm
http://3dk.asu.edu/newhome.html
http://3dk.asu.edu/DOCUMENT/archives/publication/publication.html
http://www.i3mainz.fh-mainz.de/institut/personal/boochs/
http://www.i3mainz.fh-mainz.de/db/publikationen_thema?utab=autoren&thema=Boochs.

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Tables

	small find	burial	staircase	staircase (calculated)
time	0.5h	4h	12h	4h
single measurements	8	35	200	97
max. achievable pixels	3,500,000	15,000,000	88,000,000	43,000,000
pixels calculated	300,000	11,000,000	34,000,000	34,000,000
effectiveness	9% (90%)*	73 %	39 %	77 %
average distance of pixels	0.2mm	1-2mm	5mm	5mm

Table 1. Comparison of measurement parameters from the samples.
** The small find covered approximately 10 % of the area that was measured due to the measuring field size of the cameras.*

Figures

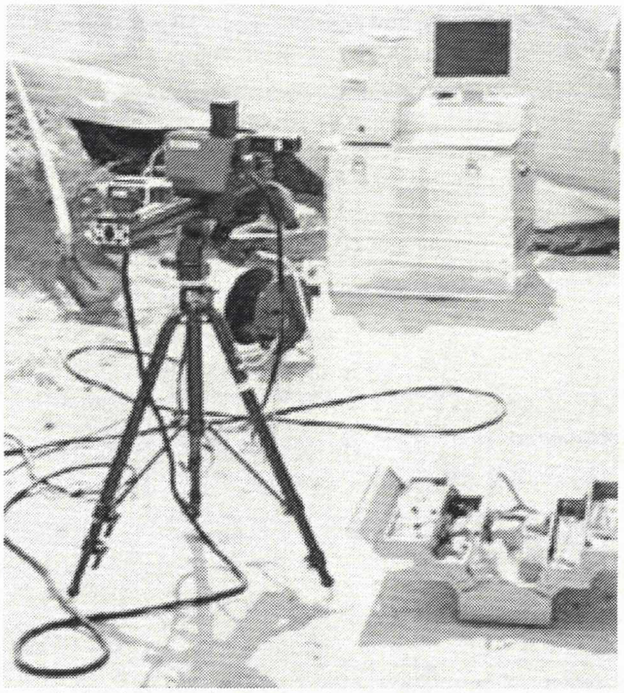


Figure 1. Equipment for measuring on site: Sensorhead with cameras and slide projector in its centre (front) and computer with frame grabber on top of a transportation box (back).

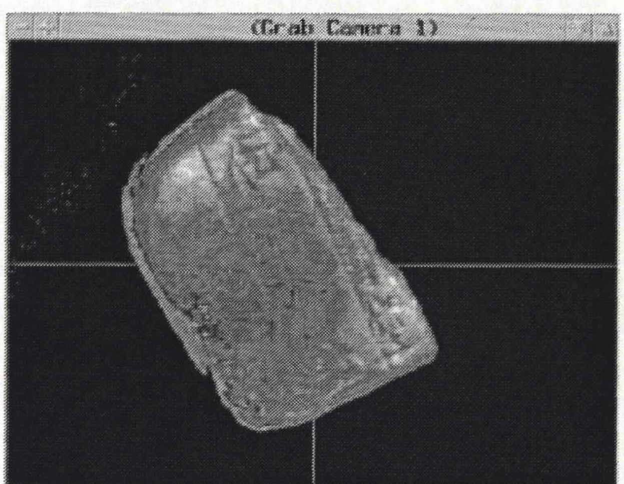


Figure 2. Adjusting the lightning for projection.

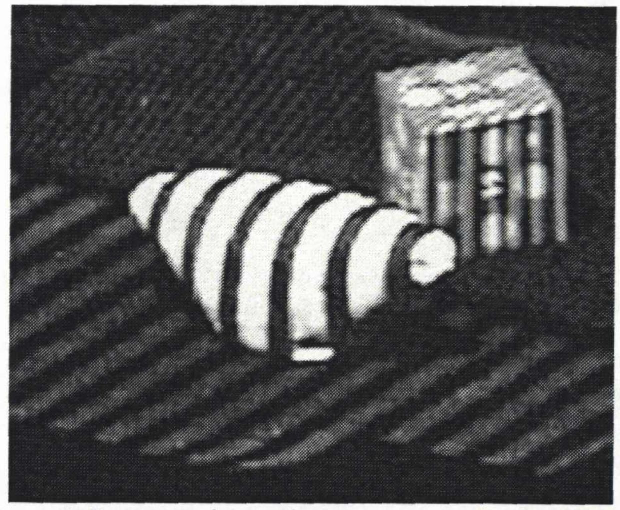


Figure 3. Projecting fringes for measurement. Back right: Reference cube for small finds.

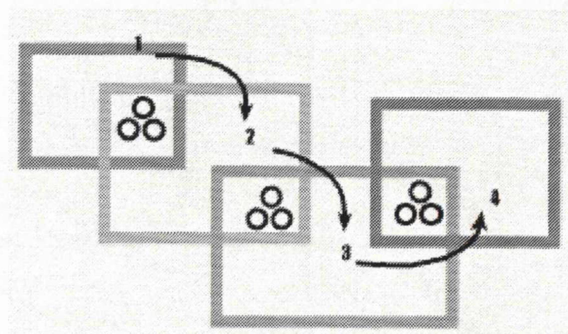


Figure 4. Covering large surfaces with reference points. Measurement steps onwards, always covering three previous and three new reference points.

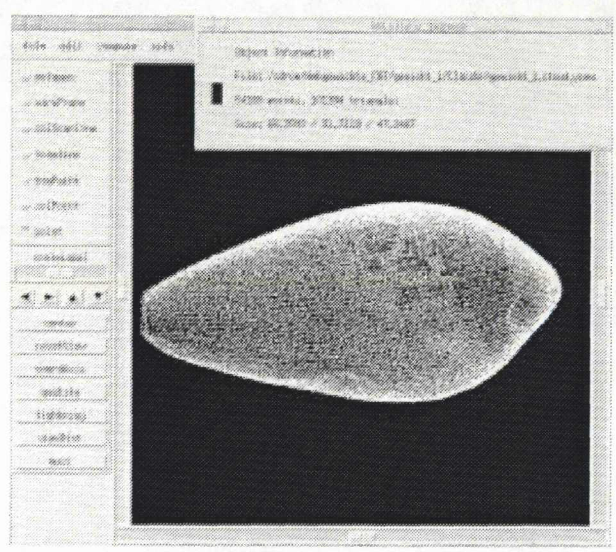


Figure 5. Controlling the final point cloud from single measurements on the screen. The viewer plots e.g. 55,000 3D-coordinates out of several million acquired and provides zooming etc.

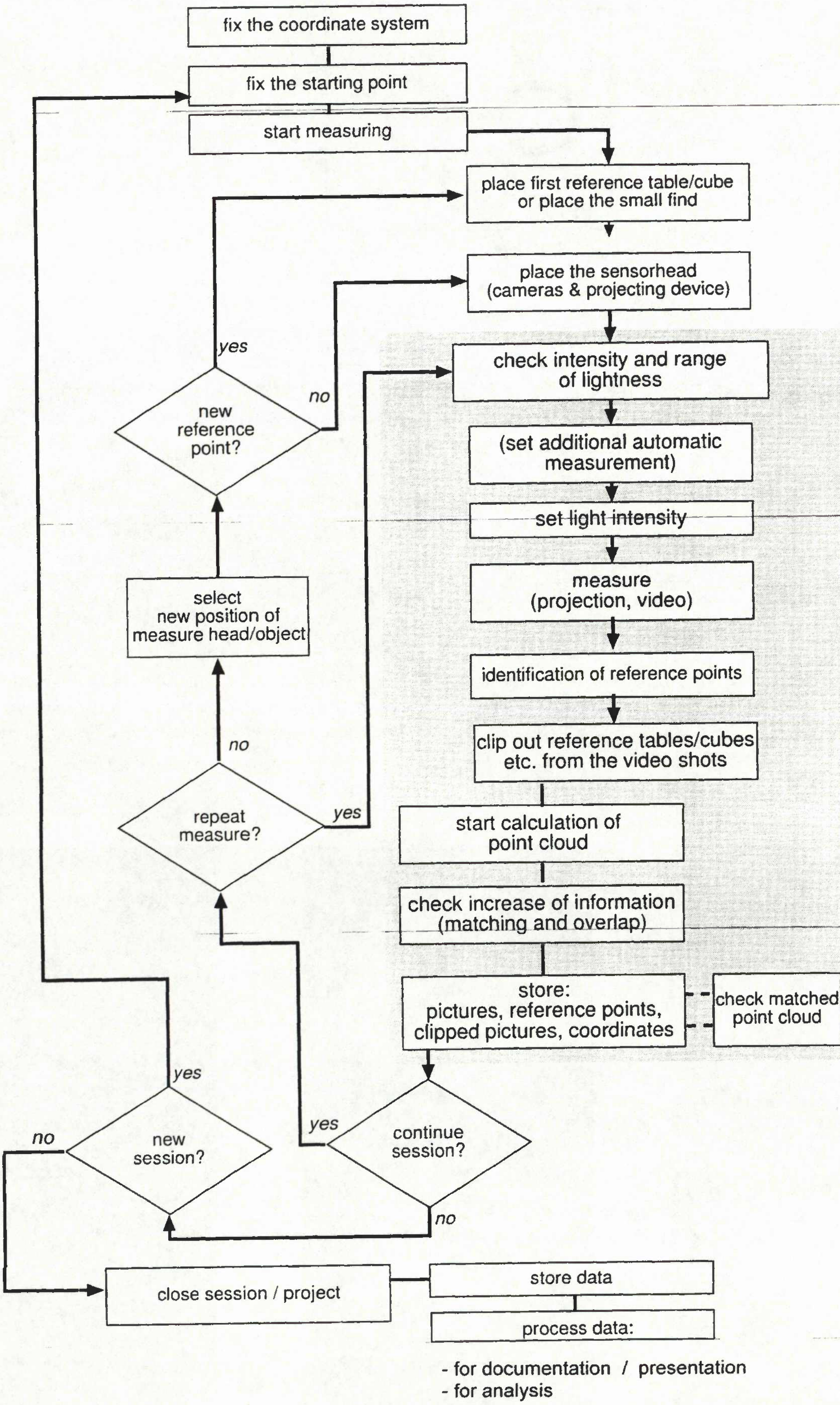


Figure 7. Steps of the measurement procedure.

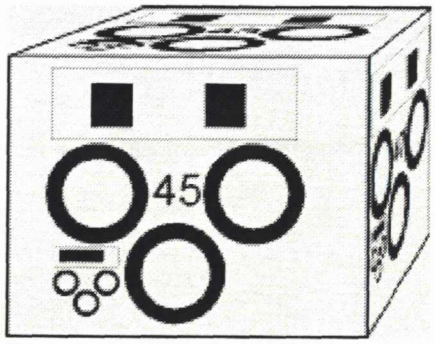


Figure 6. Reference cube.

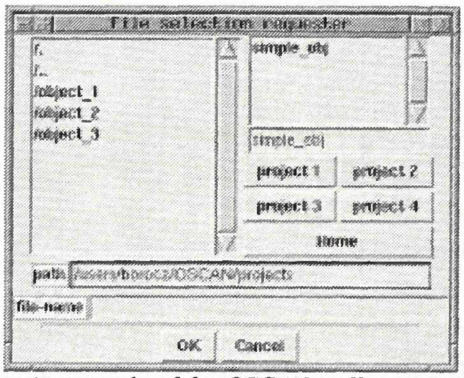


Figure 8a. An example of the OSCAN toolbox user interface. Management of measuring projects from a central control dialogue box.

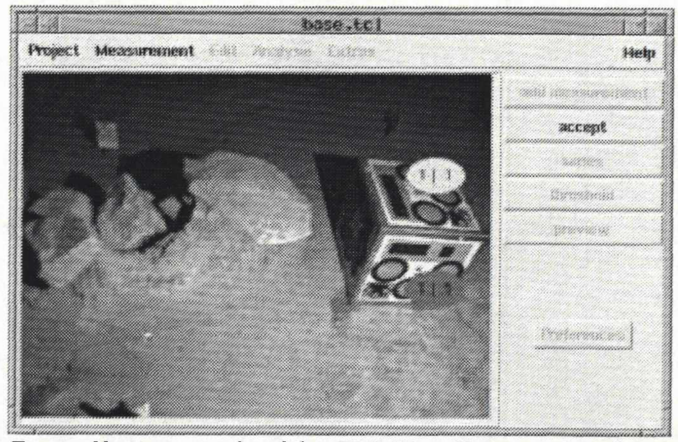


Figure 8b. An example of the OSCAN toolbox user interface. Checking the automatic identification of reference points on different sides of a reference cube in a graphic on screen.

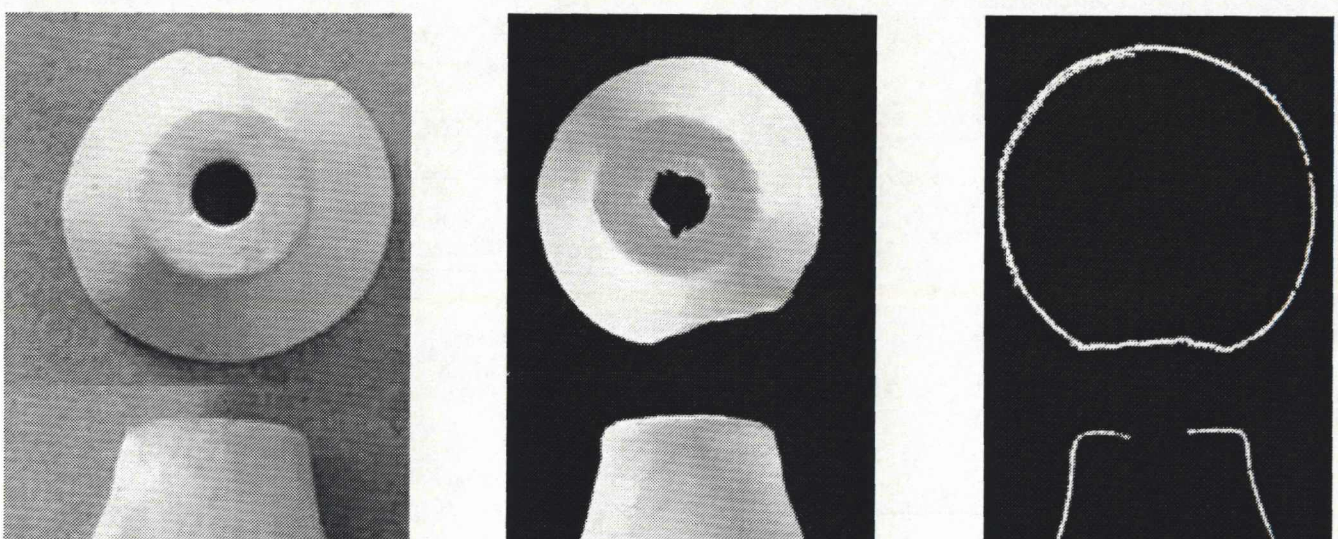
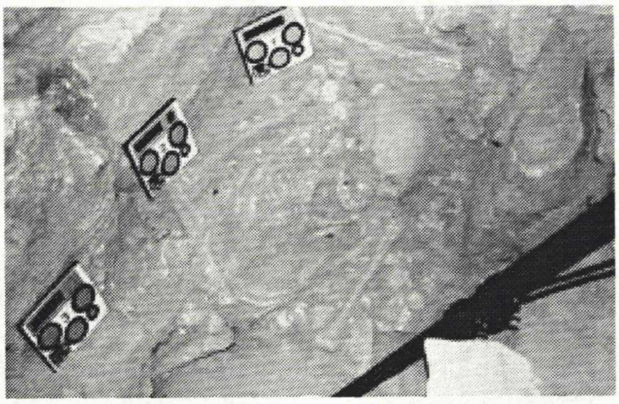
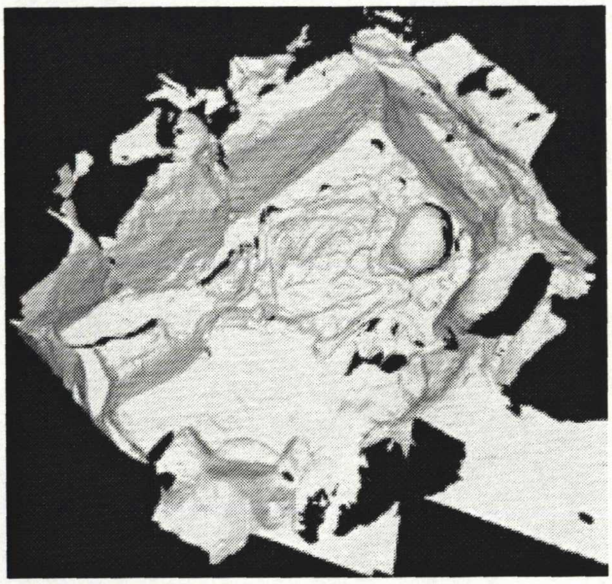


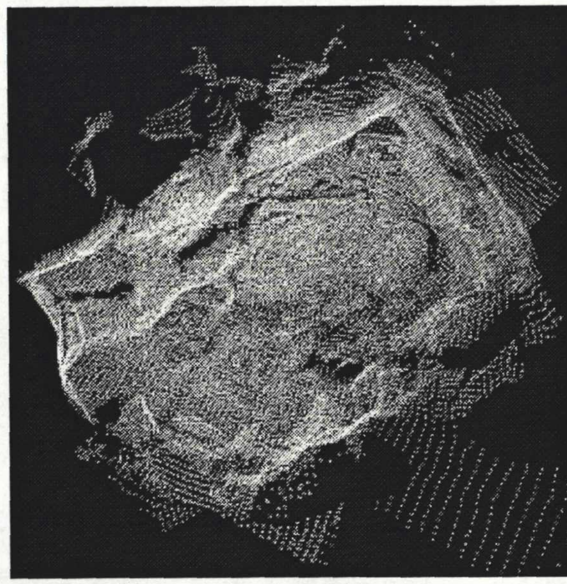
Figure 9. Small find from Tiryns, stone. (a) Photograph, (b) triangulated model, (c) cross section of the point cloud.



10a



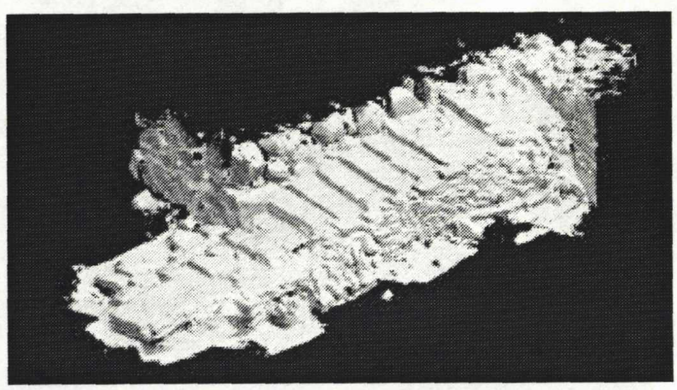
10b



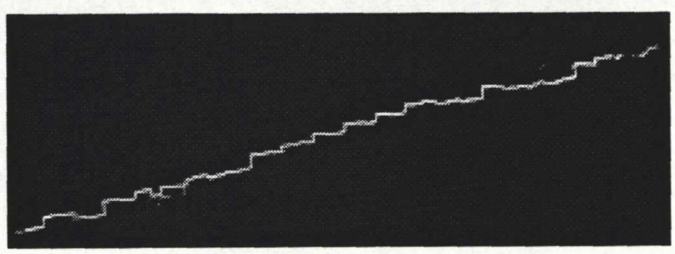
10c

Figure 10. Burial in the lower town, Tiryns. (a) Photograph, (b) point cloud, (c) triangulated model.

11a



11b



11c

Figure 11. Staircase in the Mittelburg, Tiryns. (a) Photograph, (b) triangulated model, (c) cross section of the point cloud. A video (9d) is provided on the CD.