A NOVEL SYSTEM FOR THE 3D RECONSTRUCTION OF SMALL ARCHAEOLOGICAL OBJECTS

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ABSTRACT:

The need for mapping small objects in such areas as archaeology, museum collections, medicine, and industry may be met by using close-range photogrammetric techniques. Requirements of these disciplines demand, in some instances, extremely high accuracy in an automated process for recording the geometry of objects, while in instances which involve numerous objects to be mapped an error-free but rapid procedure is necessary. Laser scanning techniques are likely the best and most reliable for these purposes. However, the costs associated with these techniques prohibit their use in many of the applications mentioned above.

The authors have constructed a device to take advantage of the properties of a laser beam; by using the optical properties of a vertical laser line beamed from an off-the-shelf laser level, standard photogrammetric methods determine locations of these points on objects. Costs are kept low because measurement is done without the use of a laser beam detector to measure distance (hence, position) of points on objects.

The cost of this system—a typical desktop PC, an electronic circuit attached to the parallel port, a digital camera, a laser level, and a rotator mechanism—is relatively low.

1. INTRODUCTION

In the matter of documentation of small artefact finds, the archaeological scientific community faces important issues that arise from several factors:

1) The objects, because often they are too fragile for repeated handling or because access to investigators has been prohibited, require special treatment in measuring, archiving, and preservation;
2) Because many small artefacts are only partially preserved, modelling and mapping are difficult to accomplish in a scale of 1:1;
3) Because the numbers of small artefacts from a single excavation may be quite numerous, it is clear that an automatic mapping procedure is needed to cut human involvement to a minimum.

Such mapping systems exist, of course, though they are often expensive and difficult to perform; however, the matters of expense and difficulty of manipulation ought not to prevent the application of one of these several modern techniques to fulfil the needs of documentation of the artefacts. The output produced by modern digitization applications will be useful in one or more of the following scenarios:

a) Internal use; i.e., the creation of a complete database archive for use within an archaeological institution or within an excavation staff for its own research;
b) Replica creation (Skarlatos, D., et. al. 2003)
c) External use; detailed study of objects by members of the academic community, who otherwise would not have direct access to the artefacts, either because access is legally prohibited or because of distance needed to travel to the location of the artefacts;
d) Creation of virtual museums; these virtual museums would provide not only digital images (2D presentations) of objects, but also accurate 3D models and visualizations using VRML object files.

2. CURRENT TREND

To date the techniques applied to the restitution of small archaeological objects are based on the exhausting calculation of 3D point clouds, which represent the outer surfaces of the objects. The most popular are (Boehler, W. and Marbs, A., 2002):

1) Laser scanning. The measuring of the 3D points coordinates is implemented through a laser beam that is transmitted towards the object and reflected back to the source. The time that is needed for the beam to travel from the laser beam source to the object and back, multiplied by the speed of laser light, yields the distance of the points from the source; hence their location on an arbitrarily defined 3D coordinates system.
2) Optical scanning. Special structured light devices and laser diodes producing straight (horizontal or vertical) line tracks are used for the exact definition of 3D points on the object. Sophisticated photogrammetric procedures may lead to the calculation of a dense point cloud that describes the outer surfaces of the objects.

Both techniques give points of nearly the same accuracy; and these are reliable for the reconstruction of the object models' outer surfaces in a 1:1 scale, though with a significant difference in cost. Laser scanners using special rotation mechanisms or mechanical arms cost about 60.000-80.000€, while optical scanners may have less, but not negligible, cost.

Several different approaches using low cost material have been proposed by universities' laboratories and individual researchers during the recent years. Among the most recent research efforts presented in the last CIPA conference in 2003 in Antalya must be mentioned two similar low cost approaches (Yilmaz, U., et. al, 2003, Pavelka, K. and Dolansky, T., 2003).

Common to the above-mentioned approaches is the use of a laser profiler, which is synchronized to the rotation mechanism and to the imaging device, in order to provide in several steps the necessary points to describe the objects' outer surface. Simple photogrammetric triangulation processes are then used to calculate the 3D coordinates of the points lighted by the laser beam.

The proposal of this paper deals with the construction and use of an optical scanning system, which has a minimal cost for both hardware and controlling software combined. Our goal is to provide an affordable device to institutions and individual researchers, which routinely suffer from small budgets (e.g. museums, state archaeological organizations, collectors, excavators). This device should allow these groups to contribute large numbers of digital objects inexpensively to the scholarly world.

3. DESCRIPTION OF THE SYSTEM AND ITS OPERATION

Almost every scanning system is comprised of three basic hardware modules, which are also the basic modules of our system:

1) Rotation unit
2) Structured light or laser pointing unit
3) Imaging unit

All the above-mentioned modules are coordinated under the control of a dedicated computer, which rotates the disk and calculates the location of the points (lighted through a laser beam to produce a vertical line) in every step of the rotation by using sophisticated photogrammetric processes.

3.1 The Rotation unit

The rotation unit consists of a specially modified turntable. A stepper motor device (fig. 1.) controls the movement of the turntable. The stepper motor used in this instance was manufactured by the AEG Company and provides 24 steps/revolution and is fully controlled through the computer's parallel port using a special interface kit (fig. 2). In order to achieve better angular resolution of the rotation mechanism the stepper motor is not directly connected to the rotational axis of the turntable, but the movement is transmitted to the axis through a special transmission belt, which multiplies the steps/revolution. As a result the angular resolution of the system provides 150-600steps/revolution.

The cost of the rotation mechanism is relatively low. The interface kit includes a Windows and DOS application that can be programmed to control the rotation of the motor. However the incremental steps of the rotation of the system is performed through the imaging software application, because the rotation, laser lighting and image-capturing processes must be fully synchronised in order to achieve the desired images for the collection of the 3D points.

Fig. 1. The stepper motor

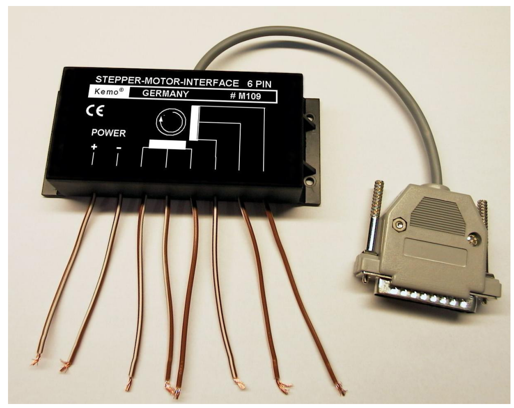

Fig. 2. The parallel port stepper motor interface kit

3.2 Laser Pointing Unit

The laser level used to create the light screen for the determination of the points to be calculated and to provide the outer surface of the object is a typical carpenters' tool used to create straight cuts. It has been altered to interpose the switching circuit controlled by the computer, between the power supply and the laser light source.

3.3 The imaging unit

The imaging unit used is the Fire-i digital Unibrain Camera. The camera is based on the Sony™ Wfine color 1/4" sensor CCD using a Built-in 4,65 mm lens with anti-reflective coating. The camera is connected through the FireWire interface port to the computer, providing a maximum of 30fps in 640x480 resolution images (pixel format YUV 4:1:1). The quality of the images adequately meets the needs for producing the 3D points (fig. 3). Additionally, the camera has no fixed focal length giving the opportunity to perform manual focusing to obtain

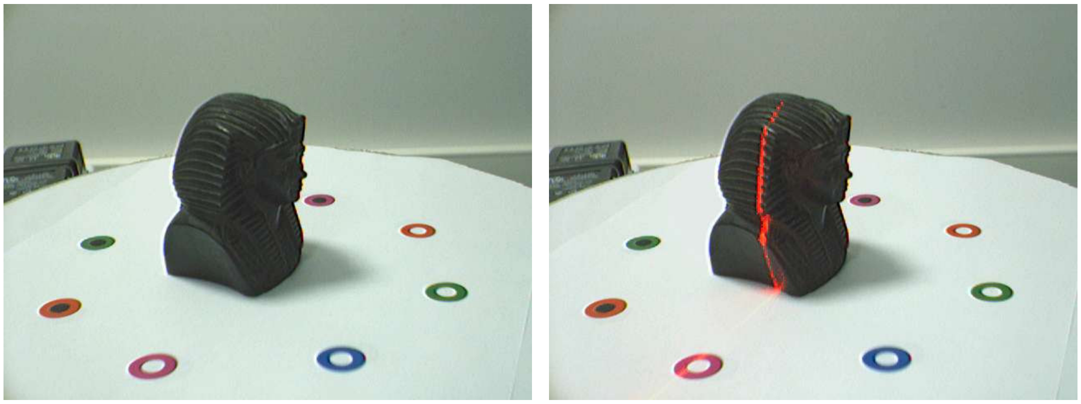

Fig. 3. The difference of the two images provide the points whose 3D coordinates are calculated

sharper images when used in very close ranges. Proper calibration has been performed to eliminate the systematic errors due to the camera's optics.

The capturing of the images is done in full synchronization with the rotation and lighting of the laser beam device so that in a single cycle of the system the following steps are performed:

Step 1) Rotation of the disk by a small angle (about 2º)
Step 2) 1st Image capture (fig. 3a)
Step 3) Switching on the laser beam
Step 4) 2nd Image capture (fig. 3b)
Step 5) Switching off the laser beam

The position (exterior orientation) of the camera during the image capturing, on an arbitrarily defined coordinate system is produced using well-defined target points located on the rotation disk (fig. 3).

The difference between the 2 images taken in the 2nd and 4th steps of the cycle gives with great accuracy the imaged position of the points that describe the object. The calculation of these points is produced with the use of a photogrammetric process since the position (exterior orientation) and geometry (interior orientation) of the camera are already known.

By repeating these steps the whole object is scanned, and a dense point cloud is created (fig. 4). The steps used to produce the calculated 3D points of the object may vary since the complexity and size of the object is also indeterminable and stochastic. The size of the rotation angle defines the spatial

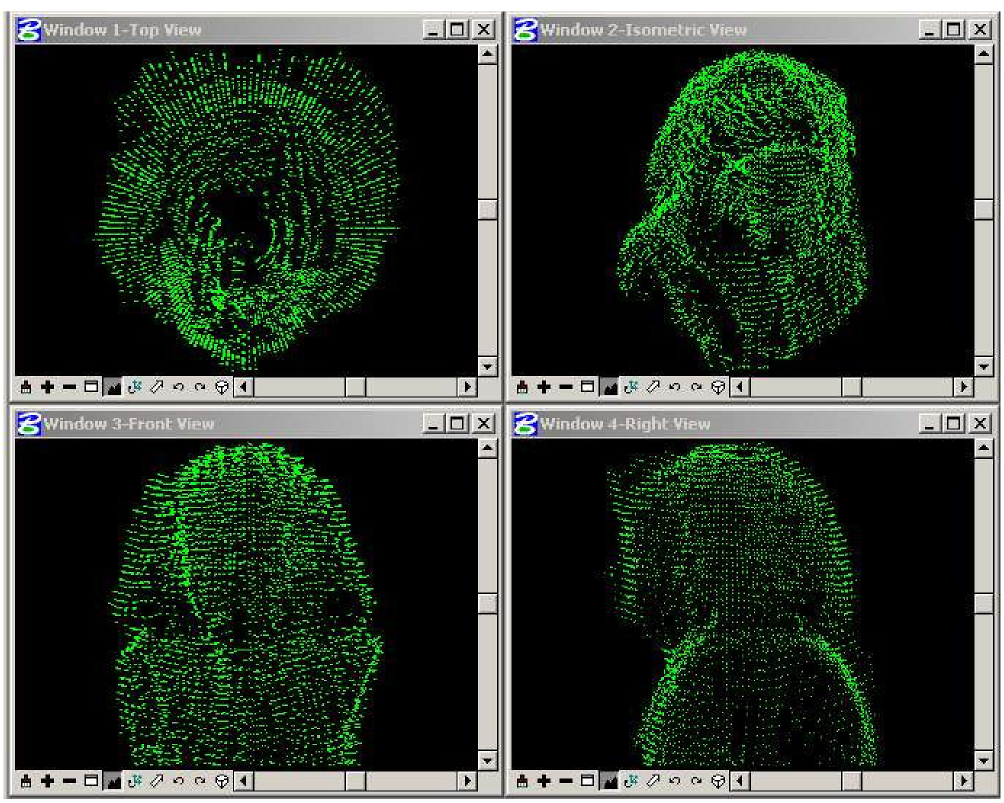

Fig. 4. Point cloud model presented in Bentley Systems Microstation

analysis along the vertical axis of the object, hence the radial analysis of the 3D model. The vertical analysis of the 3D model is defined through the ground distance of the detected imaged points lighted by the vertical laser line. In order to produce a uniform object the radial and vertical space of the points cloud should be equal.

4. ADVANTAGES AND DISADVANTAGES

The primary advantage of the device is its minimal total cost. The costs of the device is relatively low because of the fact that most of the research effort and funding were devoted to the construction of efficient photogrammetric algorithms, rather than the use of specialized hardware modules. The software application was able to

1) locate with great accuracy the position of the camera;
2) calculate the location in 3D space of the points which form the outer surface of the objects by using just one metric image

Additional use of a second imaging device (or even a third one) will provide even greater accuracy of the final results with little additional changes of the system design and its operational philosophy. The camera can be connected in a daisy chain configuration with other similar imaging devices to a single FireWire computer port, since this particular camera model is equipped with two FireWire connectors (one is connected to the host computer and the other to a second camera). In that way, by taking advantage of the relative orientation and epipolar geometry of the two cameras, greater accuracy can be created.

The main disadvantages of the system are:

1) The inability to produce a textured model of the artefacts. Future development and enhancement of the software to accomplish this aspect is under consideration.
2) The long processing time for the creation of each model. This is due to the fact that the system requires the processing of multiple images (about 150), each of which must be exhaustively scanned, in order to extract the location of the control points, which in turn leads to the exterior orientation information and determines the laser lighted points for the final calculation of the objects' exterior surface.

5. AKNOWLEDGEMENTS

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6. CONCLUSION

Because of the accurate response of the device described in this paper (along with its relatively low cost), the creation of 3D models of small artefacts in a fully automated procedure will permit the recording of items in relatively short time and will encourage museums and archaeological projects to meet obligations to disseminate data widely, thus also enabling research on otherwise inaccessible collections of cultural heritage.

Additionally, the system can be used in several other applications that demand the creation of 3D objects' model such as in medicine and industry. A case study for the use of the device in a medical application is described by Koidis (Koidis, et.al., 2004).

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