SCANNING FOR MICRONS

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ABSTRACT:

During the past few years 3D acquisition technologies have been extensively employed for the collection of three dimensional data for various applications related to Cultural Heritage. The endless variety in the material, the size and shape of CH objects undeniably calls for different approaches, in order to achieve the optimum result for the documentation process. This very need has definitely been one of the main reasons for the development of numerous systems and methods that facilitate the acquisition and processing required. Also, the trend to combine the results of the documentation of CH objects with virtual environments, educational and research applications, art and entertainment has drawn the interest of related industries that, not only increased the impact of the work that has already been done, but also have greatly contributed in the update of most related processes i.e. study, recording, processing, publication, dissemination, exploitation. At the same time, the use of high-end electronic equipment (digital cameras, lasers, projectors, strobes etc) and the ongoing increase in the performance of the hardware and software used for processing are expected to lead to remarkable results in an accelerated fashion.
In this context this paper deals with issues involving data capture, processing and e-publication of medium to small sized CH objects. These issues are addressed and analysed based on the experience of a complete case study carried out for a collection of 30 neolithic vases from the unique Dispilio lake settlement near the city of Kastoria in Northern Greece. The data acquisition and basic processing for the study has been carried out by means of a state-of-the-art structured light scanner by XYZRGB Inc., coupled with powerful proprietary software. Beginning with a short review of technologies that have been employed in the past, various well known open issues in the related processes are identified and the respective solutions/significant improvements in the workflow pipeline brought by the employment of new technologies are highlighted. The configuration of the system used is described and high resolution visualizations of sub-millimeter-accuracy for the case study are presented and assessed based on completeness, accuracy and ease of processing.

1. INTRODUCTION

The thorough study of monuments is an obligation of our era to mankind's past and future, as they are undeniable documents of world history. Respect towards cultural heritage has its roots in the era of the Renaissance. During the last 150 years archaeological excavations became common practice and reached a mature point during the 20th century. Over the recent decades, international bodies and related agencies have passed resolutions concerning the obligation for protection, conservation and restoration of monuments. The Athens Convention (1931), the Hague Agreement (1954), the Chart of Venice (1964) and the Granada Agreement (1985) are only but a few of these resolutions, in which the need for geometric documentation of the monuments is also strongly stressed, as part of their protection, study and conservation.

The geometric documentation of a monument may be defined as the action of acquiring, processing, presenting and recording the necessary data for the determination of the position and the actual existing form, shape and size of a monument in the three dimensional space at a particular moment in time (UNESCO, 1972). Geometric documentation records the present of the monuments, as this has been shaped in the course of time and provides the necessary background for the studies of their past, as well as the plans for their future.

The Geometric Recording of a monument involves a series of measurements and -in general- metric data acquisition for the determination of the shape, the size and the position of the object in the three dimensional space. Processing of these data, results to a series of documents, i.e. products, usually at large scales, which fully document the geometry and other properties of the monument. Usually such products include two dimensional projections of parts of the object on horizontal or vertical planes, suitably selected for this purpose. Technological advances in recent years have spectacularly multiplied the variety of sources for collecting metric information at such large scales. In order to fully exploit these data, special techniques are continuously being developed. Moreover, the advancements in computer industry have enabled the three dimensional visualizations of the monuments in a virtual world. The compilation of 3D models of historical monuments, large or small, is considerably facilitated by the use of dense point clouds, which are created by the use of contemporary instrumentation, such as e.g. terrestrial laser scanners. Their combined use with photogrammetric procedures, such as the production of orthophotos, allows the realistic 3D representation of complex monuments such as temples, fortifications, sculptures, vases, jewelry, etc.

One of their greatest advantages is the fact that the initial information is in 3D. This enables scientists to study the monument in its entirety at the ease of their laboratory. Considering the advancement of IT and also the fact that even theoretical scientists are even more adapted to contemporary technologies and instrumentation, the thorough study of all artifacts is practically transferred to the virtual environment, where even three dimensional measurements at very high accuracies are possible.

On the other hand, other uses are also possible by exploiting the 3D information, such as production of copies to be used as tactile models for people with vision disabilities or souvenirs. Moreover the virtual exhibition of these models may “democratize” the museum visits for a large number of people unable to travel easily. Also significant is the impact of such representations and visualizations to education, as children may familiarize themselves with museum exhibits through IT.

2. 3D POINT CLOUD ACQUISITION

This new technology has had a significant impact on how geometric documentation experts work. The very concept of field data acquisition has changed, as new means for the acquisition of 3D information came into play. Moreover, processing methods have also been modified and since large volumes of information need to be handled, the respective hardware requirements have increased. Acquisition of large point clouds, registration and filtering without loss of information, rendering with high resolution texture and 3D visualization have been one of the main research focuses of the related technical industries during the past few years.

Many different technologies have been used to build various 3D scanning devices; each system comes with its own limitations, advantages and costs. It should be noted that many restrictions are due to the properties of the various objects that are to be digitized: for example it is almost impossible to acquire shiny, reflective or transparent objects with optical system. Some of the most widespread technologies of 3D data acquisition include:

Modulated light: Modulated light 3D scanners shine a continually changing light at the subject. Usually the light source simply cycles its amplitude in a sinusoidal pattern. A camera detects the reflected light and the amount by which the pattern is shifted, determines the distance the light has travelled. Modulated light also allows the scanner to ignore light from sources other than a laser, so there is no interference.

Non-contact passive: Passive scanners do not emit any kind of radiation themselves, but instead rely on detecting reflected ambient radiation. Most scanners of this type detect visible light because it is a readily available ambient radiation. Other types of radiation, such as infrared could also be used. Passive methods can be very cheap, because in most cases they do not need particular hardware.

Photometric: Photometric systems usually use a single camera, but take multiple images under varying lighting conditions. These techniques attempt to invert the image formation model in order to recover the surface orientation at each pixel.

Silhouette: These types of 3D scanners use outlines created from a sequence of photographs around a three-dimensional object against a well contrasted background. These silhouettes are extruded and intersected to form the visual hull approximation of the object. With these kinds of techniques some kind of concavities of an object (like the interior of a bowl) are not detected.

Apart from the above, the market has been filled with various systems capable of acquiring 3D point clouds directly from the object, using laser technology. Better known are the Terrestrial Laser Scanners initially developed to survey as-built complex industrial structures, and later found great application in monuments and Cultural Heritage objects in general. These TLS systems are based on the concept of determining the time of travel of a laser beam from the instrument to the object, in order to determine the position of the targeted point. Time-of-flight or triangulation laser scanners are the most known specimens of this kind of instruments.

Time-of-flight and triangulation range finders each have strengths and weaknesses that make them suitable for different situations. The advantage of time-of-flight range finders is that they are capable of operating over very long distances, on the order of kilometers. These scanners are thus suitable for scanning large structures like buildings or geographic features. The disadvantage of time-of-flight range finders is their accuracy. Due to the high speed of light, timing the round-trip time is difficult and the accuracy of the distance measurement is relatively low, on the order of millimeters. Triangulation range finders are exactly the opposite. They have a limited range of some meters, but their accuracy is relatively high. The accuracy of triangulation range finders is on the order of tens of micrometers.

At a rate of e.g. 10,000 sample points per second, low resolution scans can take less than a second, but high resolution scans, requiring millions of samples, can take minutes for some time-of-flight scanners. The problem this creates is distortion from motion. Since each point is sampled at a different time, any motion in the subject or the scanner will distort the collected data. Thus, it is usually necessary to mount both the subject and the scanner on stable platforms and minimize vibration. Using these scanners to scan objects in motion is very difficult.

An alternative to laser scanners are Structured Light scanners. Structured light 3D scanners project a pattern of light on the subject and detect the deformation of the pattern on the subject. The pattern may be one dimensional or two dimensional. An example of a one dimensional pattern is a line. The line is projected onto the subject using either an LCD projector or a sweeping laser. A camera, offset slightly from the pattern projector, records the shape of the line and a technique similar to triangulation is used to calculate the distance of every point on the line. In the case of a single-line pattern, the line is swept across the field of view to gather distance information one strip at a time.

An example of a two dimensional pattern is a grid or a line strip pattern. A camera is used to record the deformation of the pattern and a fairly complex algorithm is used to calculate the distance at each point in the pattern. One reason for the complexity is ambiguity. Structured light scanning is still a very active area of research with many research papers published each year. The advantage of structured light 3D scanners is speed. Instead of scanning one point at a time, structured light scanners scan multiple points or the entire field of view at once. This reduces or eliminates the problem of distortion from motion. Some systems that employ such methods enable the scanning moving objects in real-time. In most cases such systems have a relatively narrow field of view that may range from a few centimeters to a couple of meters, based on the components of the system and the calibration process.

For the work carried out in this paper, a stereoscopic structured light scanner has been used. The XYZRGB Inc. SL2 system (Figure 1) comprises of off-the-shelf components. A common LCD projector is used to project the alternating patterns of light on to the object. Two cameras, either two DSLR's or two

Figure 1: The XYZRGB Inc. SL2 Scanner components

machine vision cameras, are mounted on a rigid base, which in turn sits on top of a sturdy photographic tripod. The distance between the cameras may be varied, according to the size of the object of interest. The system is driven via a laptop with proprietary software that carries out the required processing for the structured light data.

Figure 2: SL2 Scanner calibration

For the system to be operational, a calibration process must initially be performed. This procedure determines both the interior orientation parameters of the cameras and their relative position and the scale of acquisition. For this purpose a custom calibration board is imaged at various angles by both cameras (Figure 2). The software then calculates the various parameters and the system is ready for use. Scanning with the SL2 system actually involves the acquisition of 8 image pairs, as patterns of light are projected onto the object in sequence. These patterns are alternating black and white lines with decreasing width. The system calculates depth by the exploitation of the distortion of these patterns on the surface of the object. The result is a dense (up to 150μm) mesh of triangles, with points on the objects surface (Figure 3). The accuracy of the system according to the manufacturers is 50μm.

Figure 3: The resulting 3D mesh

Once the system has been calibrated, scanning is fast and reliable. However, the results are highly dependent on the behaviour of light on the surface of the object and great care should be given to the imaging parameters of the cameras. The use of suitable polarizing filters both the projector and the cameras is recommended.

3. SCANNING THE VASES OF THE DISPILIO SETTLEMENT

Dispilio is a village near Kastoria, a town in Northern Greece (Figure 4). Like the main city, Dispilio is situated at the banks of the lake of Kastoria. The area around this lake and especially its southern bank has evidence of human settlements since the Stone Age, i.e. since 5260 BC. This has been proved both by the C14 method and the study of important pottery specimens found during the archaeological digs led by Prof. G. Chourmouziadis, Professor of Prehistoric Archaeology in the University of Thessaloniki. The settlement has been discovered by chance in 1932, when after a drought period the waters of the lake retreated significantly to reveal the remnants of the settlement http://kpe-kastor.kas.sch.gr/the_lake/lake/history.htm. Prof. Chourmouziadis and his team have thoroughly studied the findings and have reconstructed specimens of the everyday life in the area and set up a museum (Figure 5).

Figure 4: The location of the Dipilio settlement

The presence of large number of decorated vases reveals, among other things, the will of the settlers to live with quality. Hence the documentation of the pottery is of utmost importance.

Figure 5: Part of the reconstructed settlement

For the purposes of an EU funded research project 3D visualizations of 30 representative vases of the Dispilio settlement were selected as the main contents of a web page (www.dispilio.org). Therefore, accurate scanning of these complex objects was required. Terrestrial laser Scanning was initially tested for this task, but the insufficient accuracy, the inadequate detail and the great levels of noise, were the main reasons for deciding to use the XYZRGB SL2 structured light scanner.

Figure 6: The photographic set up

The work was carried out inside the museum of the site, in order to avoid transferring the delicate objects. Careful handling was of utmost importance. For achieving the best results for imaging the texture, a set of Bowens Soft Boxes was used (Figure 6). For each vase a set of scans was acquired, in order to fully record all details. The final number of scans varied depending on the size and shape of each vase. Once the system is calibrated and similar objects are to be recorded, scans are acquired and evaluated regarding quality and completeness. In Figure 7 the SL2 scanner may be seen at work.

Figure 7: The XYZRGB Inc. SL2 Scanner setup

While scanning objects with such a system, the main difficulties lie with the fact that this is an optical system. In this respect, in order to obtain high quality results, the system must be fine-tuned and this can be a complicated process. As an optical system it heavily depends on a number of factors that include the lighting conditions, the focus of the cameras, the effective area of the cameras and the projector, the distance from the object, the way an object reflects light, the way an object is positioned for scanning, the camera acquisition parameters for the scans, the camera parameters for the acquisition of the texture image, flashing lights, the quality of the calibration process. Therefore, it is of great importance to first set the lighting conditions, estimate the desired field of view and accuracy, check the way various objects reflect the light and if necessary use polarizing filters, obtain good calibration results and check for camera acquisition parameters ensuring that there is rich color for the texture image and that the scan images are well exposed. Following, during data acquisition it is good practice to always process the data and check for quality for each scan and run through the data to check for data completeness once an object is finished.

4. PRESENTATION OF RESULTS

Once the scans are acquired and processes the meshes may be exported in OBJ format along with the respective texture images. All of the data are imported in GSI software, the scans are aligned, the individual OBJs are exported so as to retain the texture images for the next stages of processing, and all of the registered scans are merged. The merged data are also exported and all of the data are imported in 3D Studio Max where texture data are combined and rendered into texture maps (Figure 8). The resulting texture maps are processed in Photoshop so as to correct for tone differences and merge all of the data.

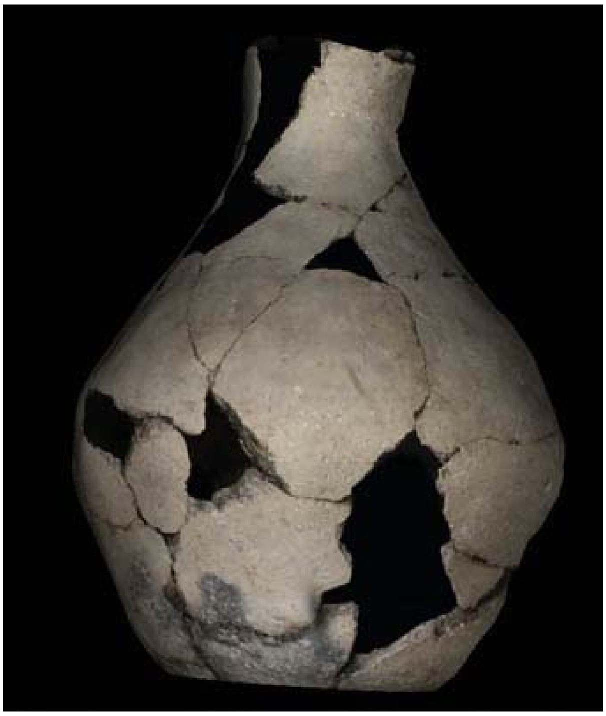

Figure 8:Sample of a rendered object

Figure 9: The environment of the VRML viewer

The final 3D models have been published in VRML format which is most easy to share over the internet. The main effort during processing is to make the surface as light as possible, i.e. less polygons, and apply a rich texture so as to have a detailed result in a relatively low size file. Cosmoplayer (Figure 9), has been selected as the suggested plug-in for the visitors of the webpage who wish to view the models through their internet browser. The visitor of the relevant webpage (Figure 10) may choose which vase to inspect with the help of the viewer.

Figure 10: The webpage interface

5. CONCLUDING REMARKS

It has been demonstrated that the 3D digital representation of small objects at high accuracies and resolutions is feasible, provided the suitable instrumentation and procedures are followed. However, all problems have not been sorted out yet and a lot of research in this field remains to be carried out.

On the other hand although structured light systems for acquiring 3D information and texture is definitely a cutting edge technology, the road to perfection is long. A lot of parameters affect decisively the final result and it greatly depends on the size, shape and the material of the object of interest. The photographic set up is of significance and a lot of care should be devoted to its perfection.

All in all and despite the various difficulties, the result is rewarding and it has already proven useful both for electronic visitors and experts.

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