OFF-THE-SHELF CLOSE-RANGE PHOTOGRAMMETRIC SOFTWARE FOR CULTURAL HERITAGE DOCUMENTATION AT STONEHENGE

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ABSTRACT:

This paper is a summary of a student internship with English Heritage's Photogrammetric Unit. During this placement affordable solutions for heritage close-range photogrammetric measurement were examined. Topcon's Image Surveying Station PI-3000 photogrammetric software was used on a project to record carvings found on one of the stones at Stonehenge. Analysis of this carving (and others) is essential in order to understand Stonehenge's history as well as to help to conserve its condition. An original survey of this carving was carried out in 1967 (Atkinson, 1968) providing context against which this survey using PI-3000 could be compared to in the future. In preparation for this work a comparison of camera calibration techniques (using PI-3000 and PhotoModeler) was carried out.

Creating a 3D model using the photogrammetric method based on a bundle adjustment requires knowledge of camera calibration parameters. Photogrammetric camera calibration parameters allow for the recovery of the central perspective bundle. They can be determined during a self calibration process if using appropriate software. It was decided to assess the camera calibration provided by PI-3000. Therefore, to test the software, a Canon IXUS 900Ti was calibrated using PI-3000 and PhotoModeler. The paper presents the results of these calibrations and compares the two software packages.

PI-3000 was then used to document a single carving found on inner face of the 53rd stone of Stonehenge. The outcome could be compared with the survey performed in 1967. Around ten images were collected with a calibrated Cannon A640 camera. Scale was introduced to the scene using a ruler laid against the stone. PI-3000 was then used to produce a meshed surface of the carving. Results will be presented.

The paper concludes that off-the-shelf photogrammetric equipment and software could be utilized in commercial projects to provide heritage recording. However, principles of close range photogrammetry still needed to be understood in order to produce high quality results.

1. INTRODUCTION

This paper reports on work undertaken during an internship with English Heritage's Photogrammetry Unit in 2007. The principal aim was twofold. Firstly, to investigate the calibration of non-metric cameras using Topcon's PI-3000 'Image Surveying Station' software and EOS System's PhotoModeler. Secondly, it was to use these cameras to generate a DSM (Digital Surface Model) of carvings visible on the fifty third stone at Stonehenge at a contour interval of 0,5 mm. These carvings were discovered by R. J. C. Atkinson (reported by Bryan and Clowes, 1997) in the early 1950s and later recorded photogrammetrically using analogue methods (Atkinson, 1968).

1.1 Surface measurement for Cultural Heritage

Stonehenge, a UNESCO World Heritage Site, is located on Salisbury Plain in Wiltshire (Southern England). It dates from prehistoric times being raised between 3,000 BC and 1,600 BC. According to some theories its stone's alignment derives from religious or astronomical origins (English-Heritage, 2010).

Detailed survey and analysis is necessary to understand Stonehenge's historic roots as well as to help to protect the site. Three dimensional reconstruction plays a significant role in this research and in the protection of other ancient cultural sites (Zheng et al., 2008). Rapidly improving and increasingly available survey techniques suited to the measurement of archaeological digs and stone carvings, such as those found at Stonehenge, now allow people to obtain more information about this great 5,000 year old monument, as well as about people living during the time when Stonehenge was erected.

The collection of surface information, which could be used for the monitoring of surface condition, is one of two important issues concerning the three dimensional reconstruction of small objects. The second is texture mapping of the surface, which could provide a photorealistic three dimensional model. Accurate measurement and a photorealistic surface model are

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necessary for an object's reconstruction process. The required accuracy of a survey is generally a function of an object's/site's size, but in the case of small carvings, which are likely to experience erosion over a number of years, the resolution must be around 1-2 mm, while the accuracy should be 0,5 mm or better (Remondino and Menna and, 2008).

1.2 Close range measurement techniques

One of the many approaches now available to measure a small surface is the application of close range photogrammetry techniques (Martos et al., 2008) using digital technology. A close range photogrammetric survey is recognised as a measurement executed by a camera situated up to 300 m away from an object (Wolf, 1983).

1.3 Image capture

Digital close range photogrammetry, in contrast to analogue photogrammetric methods and other more complex and expensive solutions, is now relatively easy to apply (Castro et al., 2004). Its ease of use arises from improvements in the performance of off-the-shelf digital cameras, increasing facilities for storing and transferring image data, the ease of image capture (without any need to use paper prints or digitising films), as well as the decreasing price of digital cameras. This is complemented by increasingly easier to use software for camera calibration and measurement, such as PI-3000 (Topcon, 2010), PhotoModeler (PhotoModeler, 2010) and others.

Therefore, close range photogrammetry now allows the recovery of three dimensional measurements with a high accuracy and it can be utilized by qualified photogrammetrists, and non-expert users. The collection of images can be very quick, limiting the time required for fieldwork. However, traditional photogrammetric theory still needs to be employed. For example, there is a need to ensure an accurate knowledge of image geometry.

For the reconstruction of an object it is necessary to measure a number of three dimensional points on its surface. The most common way of achieving this, for surfaces in a single plane, is to use stereo-pairs, traditionally with a 55% - 60% overlap, to provide a stereoscopic view. Although for small objects one stereo-pair is often sufficient, with the advent of digital image matching techniques multiple stereo-models can now be used to obtain high accuracy results. Zheng et al. (2008) note that application of multiple stereo-models with short baselines guarantees continuity of the feature on the images as well as precision of the intersection. While Wackrow and Chandler (2008) note that convergent imagery eradicates the impact of a slightly inaccurate lens model, which improves accuracy leading to recommend the acquisition of mildly convergent stereo-imagery (Bryan and Chandler, 2008).

For the purpose of photogrammetric survey, a selection of commercial digital cameras could be utilized. A consumer grade digital camera will often be supplied with an auto-focus lens and a telescopic lens. Chandler et al. (2007) provide guidances on using such cameras: *"By adopting the widest zoom setting and maintaining a camera-object distance > 0.5 m, both the largest object coverage is provided and the required camera calibration procedures are simplified*".

The accuracy of a digital photogrammetric survey is composed of a number of factors:

- Higher resolution imagery means features can be more precisely located.
- A more accurate reconstruction of the light bundle is possible if the parameters of the camera are known (camera calibration – see section 2.1 below).
- Intersection angles of 90 degrees are optimal, but could have a negative impact on image matching performance in some cases.
- Multiple images per feature (above the minimum of two) will improve accuracy if they strengthen the image network.
- Illumination angles and object radiometric texture should be sufficient to allow the application of digital image measurement techniques, improving the likelihood of sub pixel measurement.
- In most cases, even when using fast shutter speeds, the camera should be situated on a tripod to guarantee stability and limit the effects of vibration on image sharpness.

To provide the image network with scale, a known distance, visible on all images, needs to be known. It is recognised that the simplest and least expensive method of providing such control is to employ a single scale bar, which allows data to be extracted and output to a known scale (Bryan and Chandler, 2008).

1.4 The process for surface generation

Following collection of the images, software is used to orientate the images by measuring corresponding points. This preliminary process needs to be completed before the collection of three dimensional measurements and orthophoto generation.

1.5 Off-the-shelf photogrammetric software

There are now many software packages that could be used to execute image orientation, surface measurement and three dimensional modelling with very little user interaction or previous knowledge of photogrammetry. During this internship Topcon's PI-3000 was applied. PI-3000 has been applied to the measurement of small objects, historic monuments and buildings (Bryan and Chandler, 2008).

PI-3000 is designed for deriving three dimensional measurements from stereo-pairs. It also allows the generation of orthophotos and three dimensional models. Measurements are collected in stereoscopic mode, from two images taken with different angles – left and right, presenting the object of interest. It is also possible to execute the survey and object in monoscopic view. PI-3000 is quoted by Topcon as having the capability to extract coordinates for well defined points with 0.4 mm accuracy for imagery taken from 10 m distance from an object (Topcon, 2010).

2. CAMERA CALIBRATION

2.1 The importance of camera calibration

For an accurate photogrammetric survey it is necessary to determine key parameters of the camera in use. These are required by the basic photogrammetric approach that uses intersection based on the bundle method for determining the relative and absolute orientation of images and estimates point coordinates.

In order to determine the camera's true parameters it is essential to undertake a camera calibration process, generally before performing the main survey. Not knowing those parameters could lead to inaccurate measurements or even not obtaining any solution at all. Camera calibration parameters may also be determined in a self calibration process while executing the survey if using the appropriate software. In that case additional adjustment points and more images should be collected.

The parameters derived from a camera calibration are:

- The principal distance (PD)
- Principal point offset (x_0, y_0)
- 3 parameters for radial distortion (K^1, K^2 K^3)
- 2 parameters for tangential distortion (P^1, P^2)
- Terms for affinity and non-orthogonality

Although camera calibration is not a complicated task using off-the-shelf software, attention to it is required.

2.2 Camera preparation for calibration

When compared with metric cameras, the distortion of commercial off-the-shelf camera lenses can vary greatly due to a constantly changing principal distance. Therefore, a camera requires calibration for a given principal distance. Generally, for an acceptable range of object sizes and distances, the best focal length setting is the wide angle one. Automated camera features should be deactivated as far as possible, and the camera's auto focus should also be turned off.

2.3 The camera calibration processes in PI-3000 and PhotoModeler

PI-3000 (through the PI-Calib extension) and PhotoModeler offer automatic image measurement procedures for calibrating cameras. During this step, crosses on a grid are extracted automatically, as control points. The results of the image measurement process are fed into a bundle adjustment in order to solve for the exterior and camera calibration parameters. The approaches required by each of these packages are compared in Table 1.

PI - 3000	PhotoModeler
Image points occupying large part of a chart.	
Minimum of 5 images.	Minimum of 8 images (multiple angles).
Tripod necessary.	
Manual measurement of four control points required.	Fully automatic process – program measures all control points itself.
Requires an estimated focal length.	Estimates focal length itself.

Table. 1 – A comparison of PI-3000 and PhotoModeler camera calibration guidelines.

It was decided to compare the results of a camera calibration procedure using PI 3000 and PhotoModeler in order to understood the consistency between the packages and improve confidence in their use. A Canon IXUS 900 was selected for this test, being a good example of a high resolution consumer grade digital camera.

A tripod was used to ensure image stability. The camera was placed in front of the test field so as to image all of the control points on the chart clearly. The same chart was used for both software packages. The chart was flat and had 165 control points marked in a regular pattern. A number of images were collected (Figure 1) following the guidelines for each software package.

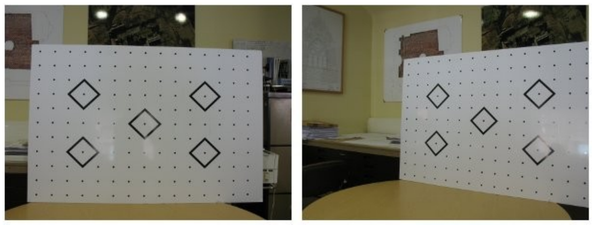

Figure 1 – Examples of images collected during the calibration process.

The key difference between the two procedures was the image network recommended by the software. For PI-3000, the chart was placed on a stand and five images of it were collected from different angles (front, left, right, top and bottom). Whereas for PhotoModeler, the chart was placed on the floor and two images were collected from each of the chart's four sides (the camera was rolled by 90 degrees at each location). In both cases image capture was quick and straightforward and could easily be followed by a non-expert user.

The results of the calibration procedure are presented in Table 2.

Parameter	PI-3000	PhotoModeler
PD (mm)	7,8065	7,7984
X_0 (mm)	3,5234	3,5084
Y_0 (mm)	2,7221	2,7203
K^1	2,43E-003	2,47E-003
K^2	-2,94E-005	-3,22E-005
P^1	-6,87E-005	-2,58E-005
P^2	1,32E-005	-2,18E-005

Table. 2 – A comparison of PI-3000 and PhotoModeler camera calibration results.

3. SURVEY OF STONEHENGE

3.1 Field work

For the purposes of the survey at Stonehenge a Canon A 640 was made available. The camera was calibrated using PI 3000 prior to the survey taking place.

The aim of the survey was to measure the shape of the carving (often interpreted to be a dagger) found on the 53rd stone of Stonehenge and to extract a surface model with contours at intervals of 0,5 mm. Previously, it had been measured using analogue methods (Atkinson, 1968) .

Field work at Stonehenge started early in the morning, with bright illumination (Figure 2). A scale was introduced to the scene by placing a ruler at the bottom of the stone, and the carving of interest was photographed with the Canon A640. This provided the survey with the known distance required during further processing in PI-3000. Cameras were placed on a tripod in order to ensure image stability. A number of images were collected, provide multiple stereo-pairs. Thanks to early start, the field work was carried out in around 30 minutes before other field projects began.

Figure 2 – Fieldwork at Stonehenge.

3.2 Surface extraction and results

The images were loaded into a new PI-3000 project and the previously determined camera calibration parameters were added. The ruler in each of the images was manually measured and the known distanced entered. Common points in the images were also identified and the PI-3000 solution was executed. The result, without further user interaction, was a three-dimensional surface, with an optional texture map. The process was completed in a matter of minutes and the results are shown in Figure 3 and Figure 4.

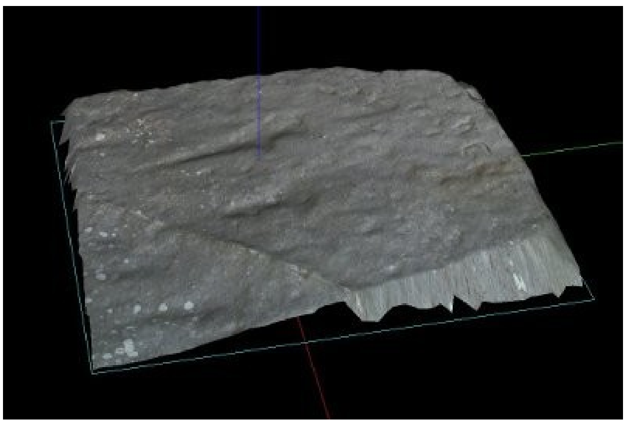

Figure 3 – Textured output following the surface extraction.

If required the surface model could be exported into commonly used data types by other software, such as for example DXF or VRML.

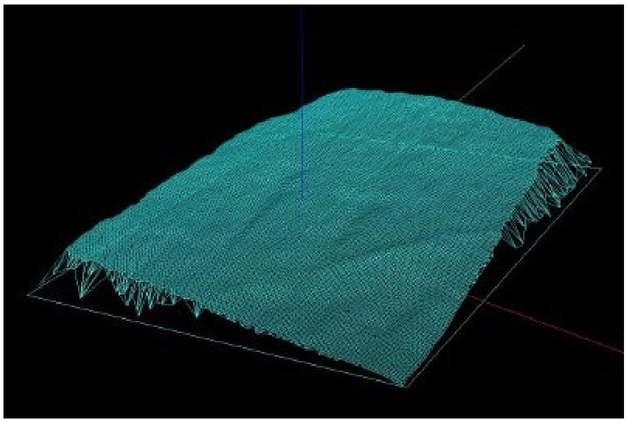

Figure 4 – Wireframe output following the surface extraction.

4. SUMMARY, CONCLUSIONS AND FURTHER WORK

4.1 Summary

The use of images obtained with digital non-metric cameras to the three-dimensional photogrammetric measurement of objects is currently of great interest (Rodriguez et al., 2008).

This paper has outlined work to record a carving on one of the stones at Stonehenge. It has discussed the use of low cost digital cameras and off-the-shelf software for photogrammetric recording. It has briefly compared the results of camera calibration using PI-3000 and PhotoModeler and described the main survey. The final output has been presented.

4.2 Conclusions

PI-3000 has a very user-friendly interface and, along with PhotoModeler, is relatively low cost when compared to other specialist photogrammetric systems. These packages make camera calibration straightforward, and the results, obtained during a like for like comparison following the manufacturer's guidelines, are comparable.

The output of the survey was a realistic and detailed model of the carving in question. This further supports the use off-the-shelf digital cameras for such measurement tasks, which is likely to lead to a reduction in the cost for the survey of such features, and an increase in the number of projects applying three-dimensional recording.

However, knowledge of basic photogrammetric principles is still required to understand the results, even if such results are often hidden from the non-expert user. Likewise, knowledge and experience would be required to overcome any problems arising – highlighting the need for the specialist skills of the metric survey professional.

4.3 Further work

Although the manufacturer claims that PI-3000 could provide an accuracy of 0.4 mm at 10 m stand-off distance, this paper has not assessed the final accuracy of the survey. Instead, it has concentrated on the process used to generate the model. An assessment against a control object or survey of a known accuracy of least 0.04 mm is required to do this.

Similarly, comparison with the 1967 survey was not carried out as the results were not available digitally at the time. If this were to be done, the lack of common control is likely to require the use of surface matching techniques. These would also be required to compare future surveys.

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