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Foreword

This volume is an extension of the printed volume “Archaeology in the Digital Era. Papers from the 40th Annual Conference of Computer Applications and Quantitative Methods in Archaeology (CAA), Southampton, 26-29 March 2012. It consists of a selection of the peer-reviewed papers presented at the Computer Applications and Quantitative Methods in Archaeology 2012 conference hosted by the Archaeological Computing Research Group at the University of Southampton, UK between 26th and 30th March 2012. The conference included 53 sessions divided between the themes of simulating the past, spatial analysis, data modelling and sharing, data analysis, management, integration and visualisation, geospatial technologies, field and lab recording, theoretical approaches and the context of archaeological computing, and a general theme. In addition there were 12 workshops. A total of 380 papers and posters were presented, and two key note addresses. Alongside the lively conference atmosphere at the venue there was a thriving social media back channel. In addition to these proceedings there is therefore a broad ranging multimedia record of the event, accessible via the conference website.

The co-organisers of CAA2012 and myself would like to thank the CAA Steering Committee for their advice and assistance. We are also indebted to Professor Anne Curry (Dean of Faculty of Humanities) and Professor Jonathan Adams (Head of Archaeology) for their support and encouragement. Many individuals and organisations in Southampton and further afield, including the sponsors and exhibitors, contributed to making the conference such a success. Of course without the many delegates travelling from across the globe and offering such exciting contributions there could have been no conference, and we are very grateful to them for their lively contributions to all aspects of the event. Finally, we would like to offer our thanks to the superb team of volunteers that made CAA2012 possible. The Archaeological Computing Research Group at Southampton was very proud indeed to be able to host the 40th CAA conference and we know that this was demonstrated by the enthusiasm, dedication and professionalism of the postgraduate and undergraduate students that gave so much of their time to the event.

I very much hope that you enjoy these proceedings and all the many related outputs from CAA2012, and I look forward to seeing you at future CAA conferences.

Graeme Earl

Southampton, United Kingdom, November 2012
Human Computer Interaction, Multimedia, Museums
1. Introduction

Traditionally the archaeological recording is based on direct measurements made upon a grid set up on field. Used as a coordinate frame it supports manual drawing done on sheets of paper. The setting out of the grid could be accomplished with the use of a theodolite. Total stations allowed not to materialize a grid on field and to consider it only conceptually. Either way, the recording is always based on the discretization of the archaeological structure towards a two-dimensional representation. In recent times, the use of terrestrial laser scanning (TLS) resulted in a much faster and reliable way of recording with the advantage of three dimensional data acquisition (Borrazás et al 2008) (Mateus et al 2008) (Costantino 2010). Usually it is either used to generate colour orthoimages or to enable direct 3D drawing. Field recording is relatively straightforward but we think it is still an expensive technology requiring an high level of expertise.

The very recent developments of automated three dimensional recording techniques based in images brought a new set of opportunities for the archaeological recording that, in some circumstances, present advantages with respect to TLS. Examples of commercial software tools that implement this kind of techniques are Image Master (http://www.topconpositioning.com/products/software/office-applications/imagemaster), Photomodeler Scanner (http://www.photomodeler.com/products/pm-scanner.htm) and PhotoScan (http://www.agisoft.ru/products/photoscan). There are also free web services - My3DScanner (http://www.my3dscanner.com/), Microsoft Photosynth (http://photosynth.net/); Arc3D (http://www.arc3d.be/), Autodesk 123D Catch (http://www.123dapp.com/catch), and freeware software available on the internet such as VisualSFM (http://www.cs.washington.edu/homes/ccwu/vsfm), Photosynth toolkit (http://www.visual-experiments.com/2010/08/19/my-photosynth-toolkit/), and PMVS/CMVS (http://grail.cs.washington.edu/software/cmvs/). All these freeware tools are based in the structure-from-motion (SFM) approach for camera orientation and in the multi-view-stereo approach (MVS) for dense point cloud reconstruction.

In this article, we present three case studies in the “Convento de Cristo” UNESCO World Heritage site in Tomar, Portugal. It was used a combination of Visual SFM - Visual Structure From Motion (Wu 2007) (Wu 2011) and PMVS/CMVS - Clustering views for...
Site Recording Using Automatic Image Based Three Dimensional Reconstruction Techniques
Victor Ferreira, Luís Mateus and José Aguiar

Multi-View Stereo / Patch-based multi-view stereo software (Furukawa and Ponce 2009) (Furukawa et al. 2009). The reason for this choice, although it may not ensure the most accurate results, is due to free access to the software and with the possibility of controlling all the process since the processing is done locally. It was also important to assess to what extent these freeware tools can provide reliable results.

First we start by demonstrating that image based techniques, such as the selected ones, can provide data with acceptable metric quality when compared with TLS, using an example where the highly decorated “Janela Manuelina” of the “Convento de Cristo” was recorded.

Secondly we discuss the case of “Pátio dos Carrascos” where those techniques were used to retrieve data for the archaeological recording. We demonstrate that the semantic quality of the data was suited to the archaeological recording. By semantic quality we mean visual qualities of the obtained materials that can be used for the archaeological interpretation and analysis.

And thirdly we discuss the case of “Paços do Infante”, where these image based techniques allowed the generation of 3D data defining a new layer of information added to a previously survey done with TLS. This operation allowed showing that both surveys have comparable performances both in metric and semantic aspects. It further allowed to visually depict the amount of excavation that was done.

2. The SFM/MVS Workflow

In general, image based three dimensional reconstruction workflow can be divided in two stages: i) image acquisition, and ii) image processing.

The first stage has to follow some specific rules to enable a more successful processing which is almost unattended with the SFM/MVS approach. It is recommended that features to be reconstructed should appear in three or more images. Images have to be redundant, and consecutive images should be taken with small base distances. The total number of images can be several hundreds. The final spatial resolution of the point cloud models is directly related with the camera distance to the object and with image resolution.

The processing stage consists on the following steps: i) feature detection in images, ii) image matching, iii) camera calibration, iv) camera orientation (relative orientation), and v) geometry reconstruction. In the SFM/MVS approach, geometry reconstruction occurs in two steps: i) sparse reconstruction, and ii) dense reconstruction. Usually, dense reconstruction uses data retrieved in the previous step as input data. The user only has to select what images are going to be processed and to define a set of parameters that will have effect on the quality and density of the reconstruction. After the reconstruction is complete, it is possible to scale and orient the model for further processing (ortho image generation, mesh generation). Until recent times these steps were done manually (Mateus 2008) (Almagro 2008) (Drap 2009). It was a cumbersome and time consuming task where an operator had to pick multiple points on multiple images. Today it is possible to perform all those steps in a fully automatic way. We may coin this form of photogrammetry as automatic digital photogrammetry (ADP).

In our examples, for the sparse reconstruction we used the software VSFM and for the dense reconstruction we used the software CMVS/PMVS. This last tool uses the processing data produced in the first processing stage by VSFM, and has two steps: i) clustering of groups of images (CMVS) and ii) dense reconstruction of 3d points (PMVS).

CMVS analyzes the image data, and tries to divide it in groups that have highly
correlated images, and with some of them also in the other groups. The maximum size of the groups is selected by the user and is dependent of several factors: image size, available RAM (critical factor), processing time. Normally, in the first time a job is processed, the user should test the group size to make sure the processing does not exceed the available RAM. CMVS creates files with processing options for each group created, so PMVS (in the next stage), knows how to process them.

PMVS is invoked, processing each group sequentially. It is also possible to divide the groups by several computers shortening the total time of processing.

There are a set of parameters that have to be adjusted in order to control the reconstruction. Some relevant parameters are level, csize, minImageNum, CPU, quad, maxAngle. Basically, with these parameters it is possible to control the downsampling of the original images, the density of reconstructions, the minimum number of images where a point as to be visible to be reconstructed, the number of CPUs to be used, the noise of the reconstructions, and the angle between homologous rays. Full documentation about the meaning of these parameters and default values used can be found in PMVS home page (http://grail.cs.washington.edu/software/pmvs/documentation.html). When starting to use PMVS, one can use it with the default configuration (that is acceptable to the average object), or change the parameters, in order to get a better result, depending on the purpose of the final model.

This automatic approach is highly dependent on the texture of objects since the algorithms used rely on matching features identified in multiple images. So, features must exist, otherwise automatic reconstruction is not possible. Usually, historic buildings are rich in textures. This can result in very dense textured point clouds that in some cases can equal or supersede, in density, the TLS point clouds.

3. Case Studies

Here we describe the image acquisition strategy, the processing workflow, the results obtained and the comparisons with the other recording techniques referred (traditional techniques and TLS). In Fig. 1 the three recorded places are identified.

3.1. Assessing the Metric Quality of a SFM/MVS Point Cloud Model - “Janela Manuelina”

One of the more known places of the “Convento de Cristo” is the famous “Janela Manuelina”. It is a very complex and detailed piece of sculpture that presents a serious challenge of recording. It measures approximately 5mx12m. To be able to accomplish a full and comprehensive photographic recording we used a telescopic mast. This enabled us to get images from higher angles, so that blind spots could be minimized. We also defined an approximate half circular pattern to displace the camera ensuring that small base distances were kept. Compliance with this principle was assured both vertically and horizontally.

The images were then processed with VisualSFM software, making a sparse reconstruction and then using CMVS/PMVS software for the dense reconstruction phase. In figure 2 we can see the feature detection in images (Fig. 2A) and the overall matching between images (Fig. 2B) here represented as a
matching matrix where the color means a level of correspondence probability.

CMVS/PMVS starts by clustering images in smaller sets that can be processed within the available RAM. Then, these groups of images, called options, are processed one at a time to retrieve dense point clouds. All the point clouds are in the same coordinate frame and have the same scale, but additional ground control points are needed to scale the final model to its real size. Table 1 shows some relevant data about this case study, namely about data recorded, hardware and software used, and processing parameters.

It is important to notice that the spatial resolution of the reconstructions is also dependent on the camera distance to the objects, meaning that closer distances allow denser reconstructions but require more images to cover similar areas. The distances from camera to object ranged from 2m to 15m. A very dense point cloud model was obtained, with more than one point per square millimetre (Fig. 3), with approximately 130 million points.

Scale and orientation were done against a terrestrial laser scanning point cloud. That survey was done with a time-of-flight (TOF) scanner with an average point density of 5mm. Twenty one homologous points between the two models were selected. From those points, scale and orientation was recovered. The registration error was about 9mm. In part, this error is due to manual point selection over reflectance laser data. Then a mesh was generated from the TLS point cloud. This mesh was set as a reference to inspect the ADP point cloud. This task was performed using MeshLab software. Before inspection, the ADP point cloud was downsampled to approximately 5mm point spacing. Using a colour code, distances were mapped in the reference mesh (Fig. 4).

Visual analysis of the results shows that generally the differences are below one centimeter. Bigger differences occur in the areas where the TLS mesh resulted from interpolation of points over void areas. This shows that an image based approach can provide reliable and

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<th>Metadata: “Janela Manuelina” case study</th>
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<td><strong>PMVS parameters</strong></td>
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<td><strong>Processing time</strong></td>
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<td><strong>Point cloud generated</strong></td>
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Table 1. Metadata about “Janela Manuelina” case study.
accurate data when compared with TLS data assumed as ground truth.

3.2 “Pátio dos Carrascos”

The need for this survey came from a demand for stratigraphical analysis in an area where an architectural intervention is being planned. An ancient pavement was uncovered with the excavation and recording was needed.

The archaeological recording is usually done stone by stone. In order to do this, a large number of points have to be identified for proper depiction of the features of each element. This can be easily done over images, for instance rectified images. However, for three dimensional objects, this technique is not very suited. In this case, ortho images are more adequate, but they require a 3D model from which to be extracted. And this, until recently, was a very time consuming task and had to be done manually or semi-automatically. To overcome this issue, we used the ADP (SFM/MVS) approach. In table 2 it is presented some data about the processing of this case study.

A 3D point cloud model was generated with approximately eight million points over an area of 110 square meters, corresponding to an average point density of seven points per square centimetre. The generated point cloud model was then scaled and oriented using four topographic control points measured with a total station and manually identified in the point cloud model. Small ink marks were painted on site to make points identification easier for the operator. The registration error was under 9mm. After this step, an orthoimage was exported and delivered to the archaeologists that used it to draw the relevant features for their analysis as it is shown in figure 5.

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</table>

Table 2. Metadata about “Pátio dos Carrascos” case study.
This example allowed us to demonstrate that the orthoimage that resulted from the automatic photogrammetric processing has both the metric and semantic qualities (as defined above) needed for the archaeological recording and analysis, that is, the archaeologists were able to recover from those images the significant data required to perform the stratigraphical analysis and the level of detail of the drawing was similar to what could be obtained by traditional techniques.

3.3 “Paços do Infante”

Also in the case of “Paços do Infante”, recording was needed because architectural intervention is under planning. A XXth century structure was dismantled uncovering XVth century walls and pavement (Dias 2012). Since the walls were approximately 10m high, a traditional survey and recording would take much time and would require a scaffold. Rectified imagery would be a possible solution but only for the walls. So it was decided to essay the SFM/MVS approach. In order to enhance image quality, reducing the strong contrast between shadow and lighted areas caused by the sunlight, bracketing was used during field acquisition of the photographs. Then, using the open source software Hugin, alignment of the images was done with align_image_stack command-line tool and exposure fusion was performed with enfuse tool (see http://enblend.sourceforge.net/enfuse_details.htm for more details). In table 3 some data on the processing of this case study is presented.

By decreasing the threshold and Wsize parameters and increasing the quad parameter, more points can be reconstructed but positional quality of the points may decrease. By decreasing the minImageNum to the value of 2, that means that it is enough that a point is only visible in two images to be reconstructed. With this the total number of points suffers a significant increase. But this also has a negative impact in the positional quality of the points. Nevertheless, sometimes this is the only way to minimize voids in the point cloud model. Changing the parameters also impacts the total time of reconstruction, as shown in Table 3.

<table>
<thead>
<tr>
<th>Metadata: “Paços do Infante” case study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camera: Canon MV1</td>
</tr>
<tr>
<td>Number of images: 103</td>
</tr>
<tr>
<td>Image size: 4200x2661px</td>
</tr>
<tr>
<td>Image format: jpg</td>
</tr>
<tr>
<td>Platform used: hand held camera and ladder for higher view points</td>
</tr>
<tr>
<td>Hardware: workstation with 48Gb of RAM and 1,28Gb NVidia GeForce GTX 570 graphics card; OS Windows 7 64bit</td>
</tr>
<tr>
<td>Software: Hugin (image enhancement), Visual SFM (sparse reconstruction) and CMVS/FMVS (dense reconstruction)</td>
</tr>
<tr>
<td>PMVS parameters:</td>
</tr>
<tr>
<td>combination 1: level=1, Csize=1, threshold=0.7, Wsize=9, minImageNum=3, CPU=18, maxAngle=10, quad=2.0</td>
</tr>
<tr>
<td>combination 2: level=1, Csize=1, threshold=0.6, Wsize=9, minImageNum=3, CPU=18, maxAngle=10, quad=2.5</td>
</tr>
<tr>
<td>combination 3: level=1, Csize=1, threshold=0.5, Wsize=9, minImageNum=3, CPU=18, maxAngle=10, quad=2.5</td>
</tr>
<tr>
<td>combination 4: level=1, Csize=1, threshold=0.3, Wsize=9, minImageNum=2, CPU=18, maxAngle=10, quad=2.5</td>
</tr>
<tr>
<td>Processing time:</td>
</tr>
<tr>
<td>combination 1: 0.25h (sparse reconstruction) + 12h (dense reconstruction)</td>
</tr>
<tr>
<td>combination 2: 0.25h (sparse reconstruction) + 2h (dense reconstruction)</td>
</tr>
<tr>
<td>combination 3: 0.25h (sparse reconstruction) + 4h (dense reconstruction)</td>
</tr>
<tr>
<td>combination 4: 0.25h (sparse reconstruction) + 12h (dense reconstruction)</td>
</tr>
<tr>
<td>Point cloud generated:</td>
</tr>
<tr>
<td>combination 1: 19.8 million points</td>
</tr>
<tr>
<td>combination 2: 21.3 million points</td>
</tr>
<tr>
<td>combination 3: 23.8 million points</td>
</tr>
<tr>
<td>combination 4: 29.1 million points</td>
</tr>
</tbody>
</table>

Table 3. Metadata about “Paços do Infante” case study.
The final point cloud model was scaled and aligned to a previously TLS survey of the site, made before excavation. Four homologous points were manually identified in both point cloud models in areas that remained unchanged during excavation. In figure 6 we have represented the site before excavation (Fig. 6A) where a TLS survey was done, after excavation (Fig. 6B) where a ADP survey was done, and the overlapping of both surveys (Figs. 6C and 6D).

The error of this registration was approximately 2cm. This may be explained by the chosen combination of parameters, particularly the “minImageNum”, leading to a more noisy reconstruction with less positional quality. Nevertheless, the overall quality of the model was suited to generate ortho images of the plans, at the scale needed, to be analysed by the archaeologists. The overlapping of both surveys also enabled a visual perception of the amount of excavation that was done, and of the position of the uncovered features (Fig. 6D).

4. Conclusions

It can be suggested that image based three dimensional reconstruction techniques (ADP), such as the ones referred, can present themselves as effective and low time consuming ways of maintaining a site recording always up to date, using only standard uncalibrated digital cameras for data acquisition. It should be added that the three dimensional reconstruction is almost unattended and automatic, what doesn’t happen with the traditional photogrammetric approaches.

One the advantages of an image based approach over terrestrial laser scanning is that it is more versatile, and in our opinion the handling of a camera is much easier even for non experts than the handling of a scanner. For instance, a camera can be easily placed in a mast, in a drone to record higher parts of a building, an underwater camera can be used in rivers or ocean sites, a macro lens can be used for smaller scale objects, and photos can be immediately processed, can be transmitted and processed at a distance, or just archived for later processing and historic reference (without the need for immediate processing). One of the disadvantages is that it is always needed extra information to scale and orient the models. This extra information can be collected with other measuring systems.

In our opinion, the possibility of recovering the geometry and texture of a site, with a method that uses standard photographic cameras, that can be easily learned, and is extremely versatile regarding the use scenarios, represents a new field of opportunities, specially for the low budget archaeological recording and analysis. Regarding the image processing, the availability of freeware, open source software and free online services, represents a democratization of the access to three dimensional processing that was not possible before.

With the appropriate setting of parameters it was shown that SFM/MVS has an acceptable metric performance when compared to TLS as it was shown with the first case study where discrepancies were generally under one centimeter. The fact that colour generation in ADP point cloud models is part of the overall geometric processing also represents an advantage when comparing with TLS. Colour is a very important quality of the data generated (ortho images for instance) for the archaeologist interpretation and analysis. Notice that in TLS colour acquisition and mapping is always an extra step of the processing.

The issue with these techniques is the hardware requirements, namely the processing performance of the computers, available RAM in the GPU (when using software that makes use of the GPU - the case of VSFM) and available RAM in the operating system (from 8GB for the smaller projects, to as many as 48GB or even 96GB for the bigger projects).
Acknowledgements

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References


