LARGE SCALE ORTHOPHOTOGRAPHY USING DTM FROM TERRESTRIAL LASER SCANNING

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ABSTRACT:

The production of orthophotographs at large scales for architectural photogrammetric applications faces a number of problems. The main difficulty arises when the ratio of the elevation differences on the object surface to the distance from the camera is large, or when there are surfaces with poor definition or little texture. In these cases the standard automatic DTM production algorithms fail to produce a useful product. A digital surface model (DSM) from laser scanning could be used as an alternative. This paper explores the contribution of laser scanner data, the improvement in the accuracy and the level of automation for the production of large scale orthophotos. A case study is presented using data collected from a 15th century Byzantine church comprising a variety of surfaces. In addition to conventional geodetic and photogrammetric data acquisition, a Cyrax 2500 laser scanner was used to collect data from varying surfaces. Comparisons between orthophotographs from conventional procedure and combined use of photogrammetry and laser scanning are made to highlight the advantage of the latter in eliminating the need for lengthy photogrammetric DSM extraction and editing, in particular for the geometric recording of monuments and archaeological sites.

1. INTRODUCTION

Orthophotography is a powerful tool of aerial photogrammetry applied in several fields, especially after the appearance of the digital photogrammetric procedures. Clearly, it has the qualitative merits of a image document and the metric attributes of a map, as it is an photographic orthoprojection. However, orthophotography is not fully accepted by the user community for applications related to geometric documentation of cultural heritage monuments. Architects and archaeologists are reluctant to concede working with orthophotographs instead of the traditional vector line drawings. As a consequence orthophotography usually is not included in the standard specifications of the geometric recording of monuments. The situation is becoming worse due to the need for special instruction for planning and executing the photographic coverage to face the problems of orthophoto production for the monuments at large scales (i.e. ≥1:100). The major of such problems are (Mavromati et al., 2002a, 2002b and 2003):

- Large elevation differences compared to distances between the camera and the object
- Presence of "vertical" surfaces, i.e. surfaces parallel to the camera axis
- Convergence of camera axes, often due to space limitations
- Failure of automatic DTM production, as all available commercial algorithms are tailored to aerial images
- Necessity for large number of stereomodels in order to minimize occluded areas
- Difficulty of surveying convex objects.

For the first two problems special measures should be taken during both field work and processing of the data. They are the main source of practically most difficulties encountered in producing orthophotographs and the relevant mosaics. The elevation differences call for elaborate description of the object's surface, in order to allow for the orthophotography algorithm to produce accurate and reliable products.

Usually, problems due to the image central projection and the relief of the object (e.g. occlusions or complex surface) can be solved by acquiring multiple photographs from many points of view. This may be compared to the true orthophoto production for urban areas (Baletti et al., 2003). However, processing can be seriously delayed for DTM generation requiring possibly intensive manual interaction or even a complete failure to produce a reliable model.

The recent appearance of terrestrial laser scanning has already shown promising contribution in overcoming such problems (e.g. Barber et al., 2002; Bitelli et al., 2002; Drap et al., 2003; Guidi et al., 2002) and also confronting other similar applications (Baletti & Guerra, 2002). The volume of points, which can be over 2 million points per scan, and high sampling frequency of laser scanning offers a great density of spatial information. For this reason there is enormous potential for use of this technology in applications where such dense data sets could provide an optimal surface description for applications of archaeological and architectural recordings.

Although laser scanning data may provide the surface models for orthophotography thus eliminating the need for lengthy photogrammetric surface extraction and editing, it is important to ensure that the resolution of a laser scan makes provision for the features of interest so that these features are visible in the resulting point cloud. Furthermore, the points in the cloud should be checked so those incorrectly measured due to multipath or mixed-pixel effects are identified and eliminated. Several investigations in the past have seriously considered this aspect and have proposed several procedures for accuracy assessment and specification proposal for integrating laser scanner data into the photogrammetric procedure, especially as far as the geometric recording of monuments at large scales is concerned (Barber et al., 2003; Boehler et al., 2003; Lichti et al., 2002).

This paper investigates the contribution of laser scanning into the production of large scale orthophotographs. A case study which is presented in this context uses data collected from a relatively small 15th century Byzantine church comprising a variety of surfaces. Two typically different types of surfaces have been chosen to illustrate the differences in the improvement of the final end products. In addition to conventional geodetic and photogrammetric data acquisition using analog cameras, laser scanning with a Cyrax 2500 laser scanner was carried out. A comparison is performed between orthophotographs produced using laser scanned data and conventional surface descriptions.

2. DATA COLLECTION

The case study presented in this paper involves a 15th century stone-built Byzantine church (Figure 1) located in the island of Tilos, in the southeast Aegean. The church belongs to the complex of the St. Panteleimon Monastery and was built on top of the ruins of an ancient temple dedicated to Apollo. As seen in Figure 1, the church is surrounded by high walls which were constructed very close to the monument for protection. The non-built area between the church and the walls is limited thus posing many difficulties in the field procedures during data acquisition. The plan view of the church is shown in Figure 2.

Figure 1. South-eastern view of the church

Photogrammetric and laser scanner data collection was performed for most external surfaces of the church. However, data only from two parts of the monument are shown here:

- the data collected from a tiled roof at the north-western part of the church, which will be referred to as “data set I” in the remainder of this paper
- the data collected from the eastern part of the church, which will be referred to as “data set II”.

The chosen parts comprise complex surfaces with intense relief, thus highlighting the advantages of integrating both types of data.

Specifically, the image data acquisition of the north-western part was performed with the semi-metric camera Rolleiflex 6006, format 5.5x5.5 cm^2 and c=40mm. Four photographs were taken which produced two stereopairs at a scale of about 1:80. The geometry of the stereopairs was adverse, due to the narrow space available and the existing obstacles in the area. The first pair (camera stations C1 and C2 in Figure 2) had an unfavourable ratio B/H=1:8, while the second pair which had a ratio B/H=1:2 (camera stations C3 and C4) was formed by converging bundles at an angle of approx. 24^o. The image acquisition for the eastern part was performed with the non-metric camera Hasselblad C/M 500, format 5.5x5.5 cm^2 and c=50mm. A total of four photographs were acquired, which resulted in two stereo-pairs. The distance of the acquired photos varied from about 10m for the first two, i.e. approximate photo scale at 1:200 (camera stations C5 and C6 in Figure 2), to 13m for the remaining two photos, i.e. approximate photo scale at 1: 260 (camera stations C7 and C8). These pairs had also a small B/H ratio, especially the second, which had a ratio B/H≈1:10, and in addition to that they did not fully cover stereoscopically the whole of the right half of the façade. All images were taken using colour slide film.

The laser scanner data acquisition was performed with a Cyrax 2500 instrument, which was mounted on its tripod during data capturing. Three scans were required to capture the north-western part of the monument with point density of 0.020m. The eastern part was captured with two scans from different locations and at a point density of 0.025m (Figure 2). An overlapping of about 40% was used to cover undercuts and hidden zones. The scans resulted to a total of about 1.5 million points. Figure 2 illustrates the locations for both camera and laser scanner set ups along with their relevant cone capture.

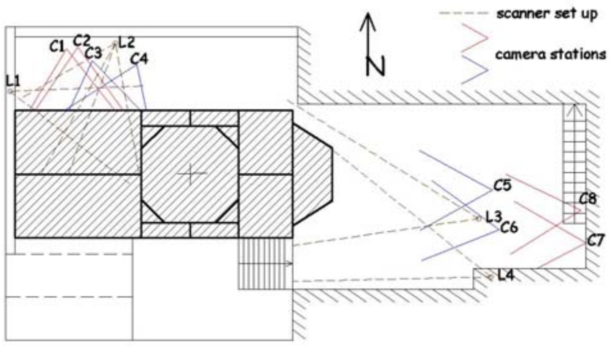


Figure 2. Plan view of the church, showing scanner set ups and camera positions (not to scale)

A general requirement for all surveys was a common coordinate system. A precise network of 16 traverse stations around the church was established using a Leica TC307 total station, resulting to an accuracy of better than 4 mm. Using these network points, about 50 control points were then measured comprising targets for the photogrammetric restitution and Cyrax targets for the point cloud registration and georeferencing. Processing of the laser scan data was performed in the Cyclone software. The registration of the data was achieved within an accuracy of about 5mm and the georeferencing within 1mm.

3. DATA PROCESSING

The acquired data from both methods were edited separately, so that the necessary digital surface models (DSM) would be created, for the orthophoto production of the north (dataset I) and eastern (dataset II) façade of the church.

3.1 Photogrammetric Procedure

All the photogrammetric works were performed with the digital workstation Softplotter v.4 of Autometric. The films were scanned with a resolution of 1600 dpi. The first processing stage is the completion of the orientations. The parameters of the calibration of the two cameras were estimated in order to perform interior orientation. Further to data processing, the relative and absolute orientation of the two blocks of four photos each, were performed. The orientations were carried out using 10 premarked targets (black and white squares) for the dataset I and 9 targets for the dataset II. Several attempts were made for performing triangulation adjustment, so as to allow estimation of the parameters with sufficient accuracy. The RMS of the resulting coordinates was less than 13mm (Kakli 2004).

The next stage included the digital surface model (DSM) extraction. The models were produced by the Triangulated Irregular Network (TIN) method, as this is considered one of the best ways of surface representation. The DSMs were produced by two different approaches, automatically as well as manually. As it was expected, the automatic approach failed to fully describe the objects' surfaces. Therefore, the only other approach was the manual editing. The manual creation of DSM involved using large number of points and a great number of breaklines, so as to define the surfaces in the best way. For data set I, which included a complex tiled roof, two experiments were made: one with a large number of points (5012 points) a small number of breaklines and one almost exclusively with breaklines (which outline all rows of tiles) and very few points. Due to the special characteristics of the object the second experiment gave much better results and the final TIN. On the contrary, the TIN for the data set II is composed of large amount of points and only few main breaklines. The points were carefully selected with a relative separation of approximately 2cm at ground scale (17315 points). It should be mentioned, that both DSMs display some gaps, since there were some parts of the objects where the stereoscopic observation was very difficult, almost impossible, due to the geometry of the bundles (e.g. the right part of the roof and the upper right part of the eastern façade).

3.2 Laser Scanning Data Processing

The processing of the scanned data was performed with the Cyclone 4.0 software. The basic processes, which were accomplished in the acquired point cloud, were the tasks of registration and geo-referencing. Registration is the critical process of tying single scans with their own local coordinate system, defined by the individual scanner location and orientation, into a combined scan. The specific software provides the capability of performing registration by two methods; the so-called cloud constraints and target constraints, or using a combination of the two methods. For data set I, a combined registration was performed by making use of the acquired 17 special targets during scanning. The final registration produced an RMS of 0.016m. For data set II at the eastern facade, there were no special targets been acquired and therefore, registration was based on cloud constraints. The registration RMS was in the order of 0.006m.

The next stage in processing included the geo-referencing or transformation of the scanned data to a common coordinate system. It is noted that the final registered point clouds were geo-referenced to the same coordinate system defined by the surveying procedure and also used in the photogrammetric process. In particular, geo-referencing of the data from the north part was performed using the special targets accompanying the specific instrument. The resulting RMS for the coordinates was less than 7mm. The geo-referencing procedure for the data of the eastern facade was performed using distinct points of the cloud with known coordinates. The RMS of the resulted coordinates was less than 1mm.

Figures 3a and 3b show snapshots from the merged point clouds of the two data sets. Clearly, there are more gaps in the merged point cloud of the north part of the church. These are due to the restricted window size of the scanner (only 40 degrees by 40 degrees) and the inability of setting up the scanner at longer distances in order to capture more details. In the same point cloud, there are evident the Cyrax targets used for registration and georeferencing purposes (in blue). Also, in Figure 3b it can be seen that the areas with no overlapping scans present many gaps in the data such as lack of features at the top roof of the church. A higher scanner set up would have prevented so many gaps in the point cloud.

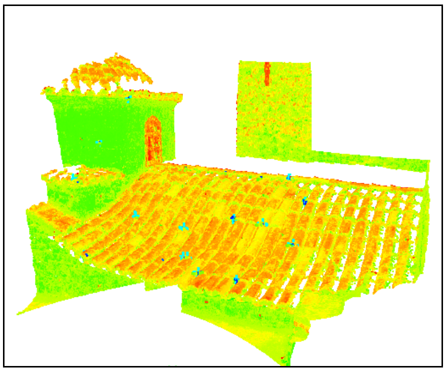


Figure 3a. Snapshot of the merged point cloud from the north-western part of the church (data set I)

Figure 3b. Snapshot of the merged point cloud from the eastern facade of the church (data set II)

Finally, the TINs of the surfaces were produced automatically from the merged and geo-referenced point clouds. However, due to the large volumes of data the resulted TIN files were difficult to manage. It was decided to implement decimation to the TIN of data set I. After a number of tests using different percentages of decimation at the initial TIN (approximately 485000 points), it was chosen to use a 15% decimation (total number of points 73000) and 50% (almost 254000 points). For the creation of TIN of the eastern facades no decimation was considered necessary (total number of points 342000).

4. ORTHOPHOTO PRODUCTION

The production of orthophotographs was conducted at the digital workstation SoftPlotter. Provided the images are already oriented, the whole process is fully automated. It is only necessary to define the pixel size. For both data sets the pixel size was set at 5mm. In total, four orthophotographs referred to the roof (data set I) and four orthophotographs referred to the eastern façade (data set II) were produced. From those orthophotos the best possible orthophoto-mosaics were produced, and are given at Figures 4a and 5a.

While processing of the scanned data was performed using the Cyclone software, this has no capability of producing orthophotographs. So, the final TINs were exported to ASCII files from Cyclone and these were imported to the Softplotter software. With the new DSMs and the reinstated orientations, new orthophotos were produced, with a pixel size of 5mm. Finally, the corresponding orthophoto-mosaics were produced for both data sets as illustrated in Figures 4b and 5b.

The visual examination of the final orthophoto-mosaics revealed that:

- For **dataset I** (Figures 4a and 4b), there were no satisfactory results for the left part of the last upper row of tiles (north-eastern side of the roof) for both methods; the problem was caused by the orientation angles of the images. Also, there was a total failure in orthophoto production of the lower right corner of the roof, because of the lack of photographic coverage. For the remaining part, the orthophoto-mosaic which was created by applying only photogrammetric procedures gave results of better quality. The existing gaps on the surface of the object due to occluded laser scanner data influenced negatively the result, regardless of the density of the data at the remaining area. It must be mentioned that the results are the same using the laser scanner data with decimation of 80% instead of decimation of 15%.

- For **dataset II** (Figures 5a and 5b), the results of both methods are satisfactory, except from some specific parts of the façade. In particular, there were small areas on the right part of the façade (at the lower level and a strip between the 2nd and the 3rd level of the façade), where no photographic coverage existed, and these are left blank in both final orthophoto-mosaics. Also, there are some weaknesses at the top of the dome, because all photo were taken from a lower level; and also at the right half of the same dome. For this area the results are better at the orhophoto-mosaic produced by using data derived from laser scanning, as the geometry of stereoscopic observation is very weak.

An accuracy control study was followed for both orthophoto-mosaics of each dataset by applying a number of comparison tests. It should be noted that all comparisons and checks were performed using points from areas of the mosaics that had no evident deformations.

Two comparative tests were made for **dataset I**:

i. the first test involved the evaluation of systematic and absolute errors of ten (10) premarked check points distributed on the two mosaics. These check points were different from the control points used during the photogrammetric process. The mosaic-coordinates of the selected points were checked against the corresponding coordinates resulted by the surveying calculations.

ii. the second test involved the check of ten (10) selected distances on the two orthophoto-mosaics. The end points of each distance are clearly defined points on the mosaics. The coordinates of those points are not measured by field surveying techniques. The distance lengths vary from 0.16-4.00 m, with random directions.

Table 1 gives the results of the two comparative tests and Figure 4c illustrates the results of the first test.

Test 1: Point errors (10 check points)		
Photogrammetrically produced orthophoto-mosaic	M_X = -2 mm	M_Y = 0 mm
	σ_{oX} = 25 mm	σ_{oY} = 8 mm
Orthophoto-mosaic from laser scanner data	M_X = 1 mm	M_Y = 3 mm
	σ_{oX} = 9 mm	σ_{oY} = 3 mm
Test 2: Difference between distances (10 distances)		
Mean of Differences	M_S = 8 mm	
RMS of difference	RMS (dS) = 9 mm	

Table 1. Evaluation of accuracy between the two orthophoto-mosaics of data set I (north-western part)

$$\sigma_o = \sqrt{[(V_i - M)^2] / (n-1)} \quad ,$$

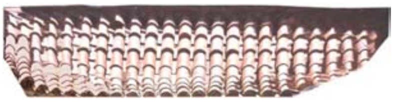
where: n - number of check points and
V_i - the difference between the i point coordinate from the surveying estimation and the equivalent coordinate from the orthophoto-mosaic (in both X, Y directions)
M_X, M_Y = the mean of the V_i differences in X and Y direction
M_s = the mean of the differences in distances.

The analysis of the above statistical results gives that:
- There is no presence of systematic errors left in the final orthophoto-mosaics either in the case of a pure photogrammetric procedure or in the case of laser scanning data collection.
- The values of the absolute deviations of the orthophoto-mosaic using laser scanner data are within the accuracy limits of the coordinates from the surveying estimation. On the contrary, the absolute deviations of the photogrammetrically produced orthophoto-mosaic are considerably larger in X direction, and give final accuracy results acceptable for scales only ≤ 1:100.
- The differences between the two mosaics are small with a total deviation less than 1 cm.

Two comparative tests were also made for **dataset II**:
i. the first test is similar to the first test made for dataset I. The check was performed for 19 premarked check points and the results are given at Table 2 and are illustrated in Figure 5c.

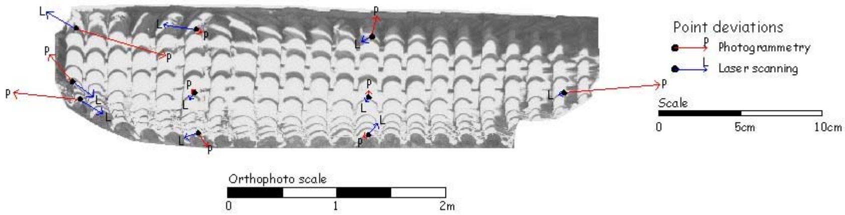
ii. the second test involved the evaluation of the relative errors of the two orthophoto-mosaics by using 26 check points, whose coordinates had not been previously calculated by surveying techniques.

The above statistical results indicate that:
- practically no systematic errors are detected at any of the two mosaics



(a) Photogrammetrically produced orthophoto-mosaic

(b) orthophoto-mosaic with laser data

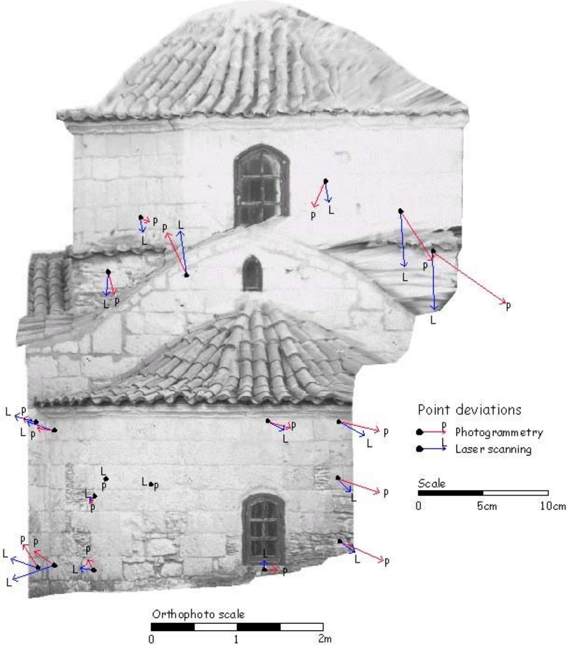


(c) evaluation accuracy

Figure 4. Results of data set I (north-western part)

(a) Photogrammetrically produced orthophoto-mosaic

(b) orthophoto-mosaic with laser data



(c) evaluation accuracy

Figure 5. Results of data set II (eastern façade)

- the deviations between the check points of the two orthophoto-mosaics are not significant. In fact, they are within the accuracy requirements for scales ≤1:100
- the comparison between orthophotos gave small differences with the best performance in the Y directon.

Test 1: Point errors (19 check points)		
Photogrammetrically produced orthophoto-mosaic	M_X = -7 mm	M_Y = 5 mm
	σ_{oX} = 20 mm	σ_{oY} = 17 mm
	Mean square value = 19 mm	
Orthophoto-mosaic from laser scanner data	M_X = 4 mm	M_Y = 1 mm
	σ_{oX} = 13 mm	σ_{oY} = 18 mm
	Mean square value = 16 mm	
Test 2: Relative errors (26 points)		
Mean of differences	M_X = 6 mm	M_Y = 1 mm
RMS	RMS (dX) = 9mm	RMS (dY) = 4mm
Max difference	max (dX) = 22mm	max (dY) = 11mm

Table 2. Evaluation of accuracy between the orthophoto-mosaics of data set II (eastern façade)

5. CONCLUDING REMARKS

The contribution of measurements obtained by the Cyrax 2500 laser scanner into the production of large scale orthophotographs has been examined. It was shown that this alternative could be a reliable choice even under difficult circumstances, as it usually happens in case of terrestrial applications, such as geometrical documentation of monuments. The capability for full coverage of the object surface with laser scanner point data, is the most critical factor for the success of this method.

In terms of the accuracy achieved in the final results of the application described in this paper it was shown that the use of laser scanned data does not substantially improve the results in comparison with the equivalent achieved by the standard photogrammetric orthophoto production procedures. This is because the derived DSM from laser scanner data is of similar or slightly better quality to that derived manually using the photogrammetric data only. However, the automatic DTM extraction from photogrammetric data can only guarantee failure for the production of the final orthophoto. The manual editing of the data can provide good results with the cost of lengthy processing procedures.

While the advantage of having a very large number of laser scanner point data is significant in the production of DSMs, the management of such dense information is not trivial. Decimation of 15% for the data set used in the DSM production has shown to produce results of similar quality with decimated sets at the level of 50% and 80%. However, when no large overlaps of scan clouds or single scan clouds have been acquired, the 15% decimation cannot guarantee reliable results.

Although in both data sets discussed in this paper, the orientation of stereomodels was performed using independent premarked points, this can also be performed through the target network required for the registration of laser scanned data or through the registered laser point clouds. In this way, it is possible to eliminate the necessary control data, which will be derived by using standard surveying techniques, thus reducing the field work.

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