A COMPARISON TEST OF METHODS AND TECHNIQUES FOR THE GEOMETRIC RECORDING OF A BYZANTINE CHURCH

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ABSTRACT

Modern ways of geometric recording of monuments offer many alternative methods for the production of vector and raster results. Not only the use of digital cameras and automated techniques but also the laser scanning point clouds were added to the classical photogrammetric procedures. The applicability of different methods and their results for the geometric recording of an 11th century Byzantine church in Greece are examined. Multiple data capturing was made by using Leica HDS2500 laser scanner, the high resolution digital camera SONY DSC-F707 and the videocamera SONY DCR-TRV80E, from ground level and from various heights using a mobile elevator. The processing of the data was done by use of in-house software, for the registration and merging of laser scanning data, the DPW SSK of Z/I Imaging, for the rigid processing of stereoscopic digital images, the DSM extraction and the production of orthophotos and also the PhotoModeler software, for the production of 3D models and orthophotos using both the digital images and specific frames from the camcorder. Multiple comparison tests were made using the following products:

- five different orthophotos of the eastern façade: three of them from SSK, using digital images, with DSM extracted automatically, manually and from LS point clouds, and two from PhotoModeler using digital images and video frames
- three 3D models: one from laser scanning data and the other two using PhotoModeler with the digital images and the video frames.

Comparisons include quality and accuracy control, with reference to field surveyed check points and distances. Conclusions were drawn for the applicability of each method or for a combination of them, concerning the details of the survey, the accuracy, the user-friendliness and the time demand for the collection and processing of the data.

1. INTRODUCTION

Modern technical specifications for the geometric recording of historical monuments and latest requirements and demands have gone over the "2D vector drawings" level, by making good use of the developments in close range digital photogrammetry and terrestrial laser scanners technology. Increased demand for raster products, especially on facades or detailed complexes, is due to the fact they offer the qualitative merits of a photographic document and the metric attributes of a map as well. Yet, despite of technological development in hardware and software issues, problems that appear during the orthoimage production of monuments at large scales, for example larger than 1:100, need special treatment both during field work and data processing as well. The combined use of laser scanning data seems to offer, under special conditions, a satisfactory alternative option to full automation in DSM extraction (Georgopoulos et al, 2004). In addition it offers a dense set of 3D point coordinates that may meet the needs for 3D partial or total modeling of the monument.

So, there is a simultaneous increase of demand both for different types of products for the geometric recording of monuments, and for the type of methods and techniques that may produce such products. Together with the use of well and long established conventional surveying and stereo-photogrammetric methods, there is an ongoing increase in the use of more automated procedures and techniques that aim to integrated 3D modeling and visualization of the monument. Each method has advantages and disadvantages, and each procedure has different special fields of good practice. For example:

- field surveying methods are more appropriate for the documentation of those monuments, where high accuracy and rather restricted number of points are needed
- stereo-restitution is widely used for the documentation of large and complex monuments, where a large amount of detail coordinates is needed
- photogrammetric rectification and orthophotography are used for the production of raster plans
- photogrammetric systems for close-range applications, based on multi-image bundle adjustment by manually and monoscopically pointing homologue points, are appropriate for the fast and easy production of 3D models and rendered visualizations (like software packages: PhotoModeler of Eos Systems Inc, 3D Builder etc)
- 3D terrestrial laser scanning is used for the collection of huge amount of 3D points, but is not convenient for edge extraction and for detailed vector drawings. There is a variety of laser scanners that might be used according to the size of the object and the scanning distance (varying between 0.1m up to a few hundred of meters), the achieved scanning accuracy (varying between 50μm up to a few cm), the operational mode of the scanner (time-of-light or triangulation scanner), the need for colour recording, etc.

In recent years, several comparative tests have been made for the 2D or 3D products of each of the above mentioned methods (Boehler, 2005), or for the combined used of photogrammetric and laser scanning techniques (Drap et al, 2003; Ioannidis et al, 2004). Despite the research made already, it is important to search further for the applicability of those methods, the quality and accuracy of their products they can give in different types of monuments. This paper gives some comparative tests in orthoimages, 2D vector drawings and 3D models of a monument, that have been produced by using commercial instruments and systems. The objective of this study is to examine the capabilities of data fusion (photogrammetric measurements - terrestrial laser scanning data), and photogrammetric software for architectural applications that create 3D textured models, in geometric recording of monuments.

The test field for the above study was the Byzantine church of Samarina (Figure 1). The church was build, in the 11th century by the queen of Byzantio Theodora, on the ruins of an ancient temple. The church is located in the Prefecture of Messinia, in the Southeastern part of the Peloponnese, in Greece.

Figure 1. A general view of the church

2. DATA CAPTURE

The comparison tests that are described in this paper are the byproduct of a project accomplished by the Laboraty of Photogrammetry of NTUA, with the support of the Mayor of Androussa, of the local municipality area. The project includes the full geometric recording of the Byzantine church, the production of vector and raster plans of the facades, horizontal sections and finally a 3D textured model. Comparison tests have been made by using only the data of the external eastern façade, which is the one with the most significant relief.

Many more measurements than the necessary for the recording of the outer side of the church have been made and a variety of data captured. These include:

- A network of 12 geodetic stations, measured with a Total Station.
- Capturing of 134 digital images was made, from distances that vary between 8-10m from the object, using the SONY DSC-F707 camera of 5 Mp, with a resolution of 2560×1920 pixels. The flat surfaces of the church were covered monoscopically; those with a relief such as the roofs and the dome, stereoscopically; while some extra images were taken, with appropriate convergence angles (of 20o-90o), for the application of PhotoModeler software. 197 control points and 47 check points were presigned and surveyed with an accuracy of ±4mm.
- A video recording of total duration of 40 min was made for the whole external surface of the church, from distances 5-6m from the object, by using Sony DCR-TRV80E 2Mp videocamera, whose frame resolution is very low: 320×240 pixels.
- Laser scanning of the church was made by using Cyrax 2500 (Leica HDS2500) terrestrial laser scanner, from 14 locations of the scanner, with a point density of 1cm in the surface of the object, and a significant overlap between the scans. 45 flat reflective targets were placed and surveyed.

Images, video and laser scanning of the high parts of the church were taken by using a mobile elevator, from heights varying from the ground surface to between 5-20m; special attention was given to the stability of this platform.

3. METHODS AND RESULTS

3.1 Laser scanning data

For the full coverage of the eastern side 4 scans were necessary; two from the ground surface and two from a higher level by using the mobile elevator. Figure 2 shows the scanning data from one location of the scanner; it obviously includes more information than is necessary for the comparison tests in the eastern facade.

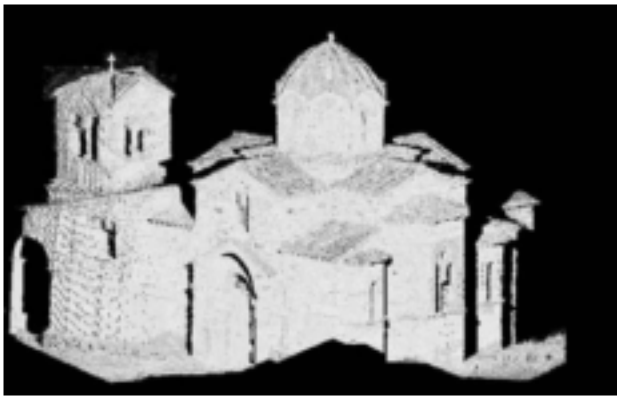

Figure 2. Laser scanning point clouds taken by using the elevator, from south-eastern direction

In order to achieve more accurate and reliable results, a simultaneous registration and geo-referencing of point clouds, through the geodetically measured targets, was made. A coordinate reference system, with its X and Z axes parallel to the basic level of the eastern side, was established. All geodetic measurement calculations were made in this system. Data processing and 3D similarity transformations of the point clouds were made by a special software, which was written in the Laboratory of Photogrammetry of NTUA, in MatLab environment. The final distortions in registration were of a few mm, with a given laser scanner accuracy of ±6mm in 50m. Special care was given to the possibility of quick data processing of the huge volume of scanning files.

It was calculated that similar level of accuracy in registration procedure may be achieved by using, as targets, the pre-signed control points, which were placed for the photogrammetric processing; it is assuming only that a fine scanning, with a density of 1mm, in the neighborhood of each control point will be made, exactly as it is made for the reflective targets. The only difference is that no automated point recognition can be made. Nevertheless, during the point clouds processing, the manual recognition of the location of each one of those points is easy. By this method, the use and survey of additional target points can be avoided, in cases of combined use of photogrammetry and laser scanning.

The next stages of the processing refer to the automatic creation of TINs of the surfaces and finally to the 3D model production, by using the commercial software Geomagic. In addition, an attempt was made to compile vector drawing of the eastern façade directly from the seamless point cloud, in AutoCAD environment. The well known problem of the difficulty in edges recognition and extraction, did not hinder the production of a satisfactory result considering both the detail completeness and the level of accuracy of the basic dimensions of the façade.

3.2 Data processing in a Digital Photogrammetric Work-station

The traditional photogrammetric processing using DPW includes, for the eastern facade, the stereo-restitution of 6 pairs (from 9 images) of high-resolution digital images. The significant relief and the existence of surfaces which are almost vertical to the basic surface of the façade, have been the critical factors which:

- increased the difficulty in achieving similar level of

accuracy in the orientations of all stereo-pairs,
- burdened the full stereoscopic coverage of the façade, and
- finally reduced the quality of the ortho-mosaic.

Digital surface model, breaklines and finally the complete vector drawing of the façade were derived from the stereo-restitution. In order to avoid occlusions, rectification was made in two small flat areas in the upper part of the façade. For the comparison tests, the orthophoto-mosaic was produced following three different techniques for DSM extraction, using:

1. breaklines and manual DSM with point density of 7.5 cm
2. automatically extracted DSM at a grid of 5 cm
3. as DSM the final unified point cloud from the laser scanning (without breaklines), since it belongs to the same coordinate system with the photogrammetric model.

3.3 Photogrammetric software for 3D model production

As an alternative solution for the fast and easy production of 3D textured models using photogrammetric procedures the PhotoModeler software was used. It is almost a "black box" for the user, which offers a simplified user-friendly interface, using in the background photogrammetric algorithms of multi-image management mainly with bundle adjustment. Coverage of all object points with two or more images that have been taken from proper angles, with a desired convergence of 20o-90o, is needed (Figure 3).

Figure 3. Location and measurement of homologue points in PhotoModeler

The main problems are the lack of any kind of automated procedures, as e.g. matching, which increases the required workload, and the insufficient ways for the assessment of the achieved accuracy. However, it is a cost effective solution with interactive processing for the 3D geometric recording of monuments, without any need for special knowledge of photogrammetry. The PhotoModeler package has the ability of:

- self-calibration or introduction of interior orientation parameters, for the use of non-metric cameras
- the use of lines between points for the determination of the delineation of the objects or imposing constraints, such as collinearity or coplanarity of points
- determining epipolar lines facilitating the location of homologue points
- producing orthoimages at defined projection planes
- creating TIN and wireframe models and applying texture to the model
- 3D viewer, with zooming, rotating and measuring capacity on the model.

For the eastern facade of the church, two projects were created in PhotoModeler: one with 26 digital images of the Sony camera and another with 78 selected frames of Sony video. The second was made exclusively to clarify the results of the combined use of a software package, which is to address the needs of non photogrammetrists, and of an amateur camcorder, which is used broadly for documentation purposes. Earlier research on the use of a similar resolution camcorder for conventional orhophoto production of monuments has shown the limits of the method. (Tsiligiris et al, 2003).

The results of each project were the production of a mosaic of orthoimages (e.g. Figure 4), and of a 3D textured model (e.g. Figure 5) of the facade. A first conclusion is that, due to the difference in resolution and size of the images, the project using high resolution images was finished much more quickly than by using video frames, since points were more clear in that and the images needed for the creation of the model were fewer in number.

Figure 4. Ortho-mosaic produced with PhotoModeler using the digital images

Figure 5. 3D textured model produced from the PhotoModeler using the digital images

4. COMPARISON TESTS

As it is already described, five orthoimages of the eastern façade were produced by different independent procedures: three by using the SSK and two by using PhotoModeler. The comparison test between those products includes control of accuracy and quality.
The accuracy control was made:

- for each orthoimage, by calculation of the check point coordinate deviations from their geodetically determined values
- between the orthoimages, by comparison of 40 distances between unknown but well-defined characteristic points scattered over the surface of the façade. Fifteen (15) of those distances have an almost horizontal direction (parallel to axis X), fifteen (15) almost vertical, and the remaining ten (10) random direction. Their lengths vary between 3-15 m.

Ortho image	Number of CP	mX (cm)	mZ (cm)	r.m.s. X (cm)	r.m.s. Z (cm)
1. SSK manual	36	0.5	-0.3	1.9	1.8
2. SSK auto	21	-0.4	-1.1	1.7	1.7
3. SSK laser	36	-0.2	-0.5	1.2	1.3
4. PM images	36	0.2	-0.1	0.6	0.3
5. PM video	21	0.1	-0.3	1.8	3.0

Table 1. Evaluation of orthoimage accuracy using the check point coordinates

Table 1 shows the results of the statistic control for the coordinates of the check points. mX, mZ are the mean values of the deviations along X and Z axes, and they are indicating the existance of a systematic error. It seams that only the othoimage that was produced in SSK with automated DSM, has a small systematic error of the size of 1cm for the elevations. Rms (X, Z) values can show that the most accurate orhoimage is the one produced in PhotoModeler with the high resolution digital images, where the deviations are of the size of 0.5cm (accuracy of 1:25). In all the remaining orhoimages similar deviations are calculated, which vary between 1-2 cm along each axis. Some slightly larger errors are detected in the orthoimage derived from the video frames.
The accuracy control of distances included the following five relative comparisons:

A. between orthoimages 1 and 2, that is produced in SSK with manual and automated DSM extraction
B. between orthoimages 1 and 3, produced in SSK with manual DSM and LS point clouds
C. between orthoimages 1 and 4, produced in SSK with manual DSM and in PhotoModeler with high resolution digital images
D. between orthoimages 3 and 4, produced in SSK from the LS point clouds and in PhotoModeler with high resolution digital images
E. between orthoimages 4 and 5, produced in PhotoModeler with high resolution digital images and video frames.

Table 2 shows the results of this control. ΔS differences were calculated for each distance in both orthoimages that are compared each time. Then, the mean values of ΔSi (mSX, mSZ and mSR) are calculated, which indicate the existence of systematic deviation between the two orthoimages, and $\sigma o=\sqrt{[(\Delta S_i-m_i)^2]/(n-1)}$, for the assessment of their accuracy. Last column of Table 2 shows the results for all forty (40) distances, while the other columns give separately the results for the distances along X axis (symbol SX), Z axis (symbol SZ), and in random directions (symbol SR).

	m_{SX} (cm)	σ_{oSX} (cm)	m_{SZ} (cm)	σ_{oSZ} (cm)	m_{SR} (cm)	σ_{oSR} (cm)	σ_{oS} (cm)
A	0.9	1.7	-0.1	1.8	-0.1	1.1	2.0
B	0.6	2.3	0.2	1.9	0.2	1.6	2.0
C	-0.9	2.4	-0.5	1.5	0.5	0.9	1.8
D	0.1	1.3	0.1	1.7	0.8	1.6	1.6
E	0.2	2.1	0.6	2.3	0.8	2.1	2.1

Table 2. Evaluation of orthoimage comparative accuracy using distance measurements

It is proved that there are not systematic deviations between the compared orthoimages: mi values are at the size of the expected accuracy of each orthoimage (<1cm). Also, in all controls, the distance deviations were independent of their length, thus showing that there is no difference of scale between the orthoimages. Differences in accuracy of the orthoimages are rather small, of the size of 2cm (max 3cm), and smooth despite the variety of methods and procedures applied for their production. Comparatively larger deviations are detected in the horizontal distances. In total, the smaller differences are detected in comparison D (between orthoimages 3 and 4), proving the results derived from the accuracy assessment of the check points. On the contrary, orthophotos 4 and 5 (comparison E) show large differences, despite the fact that they have been derived by using the same software (PhotoModeler), thus proving the importance of the quality of the images used.

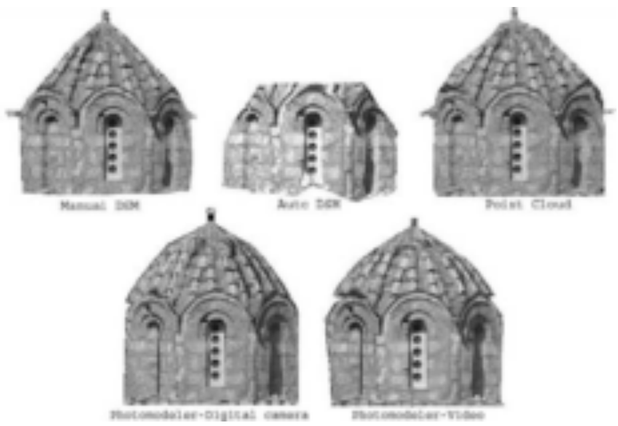

Figure 6. Presentation of the dome in the five orthoimages

As far as the quality of the images is concerned, this can be assessed as quite satisfactory. The biggest problems are detected in the presentation of the dome, which has the most complicated shape and it is located far behind the basic surface of the façade (Figure 6). Some more specific comments for the orthoimages are the following:

- Orthoimage (1), produced using the manual DSM, has small distortions on the ceilings, where are the seams among the orthoimages produced from the lower and the upper strip of images. Some image discontinuities are also detected in the basis of the dome, where the stereoscopic observation is not possible.
- Orthoimage (2), produced with the automated DSM, has significant distortions at the upper part of the dome, where automated matching failed. Distortions are also detected at

the edges of the façade due to the step of DSM and the lack of breaklines.

- Orthoimage (3), produced by DSM from the point clouds, has small distortions in particular parts, where there was no correspondence between the points that are shown in the image and those of the cloud. It should be noted that despite the fact that the production of such an orthoimage is supposed to be an automated procedure, it can be especially time consuming if a strict planning of image capturing and laser scanning is not followed.
- Orthoimage (4), produced from PhotoModeler using high resolution images, has no serious distortions. If local distortions do exist, this is due to the fact that no special attention was given to the correct and accurate determination of the surfaces, and the points that define them, in those locations.
- The same comment is valid also for Orthoimage (5), produced from PhotoModeler using video frames. The distortions in this case are more due to the low resolution of the images and the difficulty in the detection or location of the homologue points.

4.2 3D models

Similar accuracy and quality controls have been made among four 3D models of the church, which have been created by different independent procedures. All controls have been focused on the eastern façade area, where geodetically measured check points have been used. The four models have been produced:

- model 1: through a typical photogrammetric procedure, that is the 3D data of a stereo-restitution in SSK
- model 2: by modeling the merged laser scanning point clouds
- model 3: by PhotoModeler using high resolution images
- model 4: by PhotoModeler using video frames.

Accuracy controls were again of two kind:

- calculation of systematic and absolute errors, through deviations in each model of 13 check point coordinates scattered over the façade area (Table 3)
- determination of relative errors among models, by calculating the differences in the coordinates of 30 unknown but well defined points and in the length of 10 selected distances as well (Table 4).

3D model	m_X (cm)	rms X (cm)	m_Z (cm)	rms Y (cm)	m_Y (cm)	rms Z (cm)
1	0.5	1.5	-0.2	1.0	-0.7	2.5
2	0.2	1.4	-0.3	1.0	-0.2	1.1
3	-0.2	1.4	0.2	1.0	0.3	2.1
4	0.1	2.2	1.1	1.1	0.1	2.4

Table 3. Evaluation of the accuracy of 3D models using the check point coordinates

According to the results of the controls, shown in Table 3, no significant systematic error is detected at the coordinates. Only at the elevations of model 4 (produced by PhotoModeler using video frames) a systematic distortion at the order of 1 cm are detected. In general all model accuracy is considered to be satisfactory for all possible applications in the field of recording and visualization of monuments. Bigger deviations are shown, as expected, in the third dimension (along Y axis), that is the distance of the camera or laser scanner from the object. Where photogrammetric procedures are used, these deviations are approximately 2-2.5 cm (accuracy of the scale of 1:100), while with laser scanning they are at the scale of 1:50. Comparatively bigger distortions are detected in model 1, which was produced from data of stereo-restitution, and they are mainly due to local problems created by the image geometry and to smoothing of data for the creation of the surfaces of the 3D model. On the contrary, modeling from laser scanning point clouds (model 2) gives the most accurate results; this is due to the huge amount of available data and to the fact that no processing of the primary data, for the production of 3D information, is needed.

The results of the two models produced by PhotoModeler are of significant interest. Using digital images of high resolution (model 3), accuracies are of the same or better level with those of stereo-restitution model (with same primary data); however, the instrumentation cost is much lower and, also, additional possibilities are provided for simultaneous modeling and extraction of textured products. Low image quality in model 4 obviously has an impact on the accuracy of the model but this can rather be considered as not remarkable. It should be noted though that check points are well defined characteristic points of the object; thus minimizing the impact of a possible error caused by inefficient determination and matching homologue points.

Controls among 3D models include the following four comparisons:

I. between models 1 and 2, that is from stereo-restitution in SSK and from laser scanning
II. between models 3 and 2, from PhotoModeler using high resolution images and from laser scanning
III. between models 3 and 4, from PhotoModeler using high resolution images and using video frames
IV. between models 3 και 1, from PhotoModeler using high resolution images and from stereo-restitution in SSK.

Table 4 shows the results, where:
ΔS = rms(Si-Sj) are the differences in distances in models i, j
mX
ΔXS=rms(Xi-Xj) are the mean values and rms of differences of X (or Z or Y) coordinates in models i, j

Check	ΔS (cm)	m_X (cm)	ΔX_S (cm)	m_Z (cm)	ΔZ_S (cm)	m_Y (cm)	ΔY_S (cm)
4.5	0.1	1.8	-0.7	1.4	0.1	2.2	
1.6	0.0	2.0	-0.5	1.7	-0.2	1.5	
1.8	0.3	1.5	0.7	2.1	-0.4	1.6	
5.1	0.2	2.5	-0.1	1.2	0.4	2.4	

Table 4. comparisons of point coordinates and distances in 3D models

It can be derived from Table 4 that there are no significant systematic differences in point coordinates that create the models; mX, mZ, mY values are of the same order with the accuracy of point coordinate determination (a few mm); thus proving the correctness of the conclusions derived from all previous controls. The relative coordinate accuracy of controlled points varies between 1.5-2.5 cm, and is similar to the level of the absolute error in the coordinates as this is derived from the controls of check points with known coordinates (see Table 3). Consequently, the accuracy of detail points in various models is of similar level. Unexpectedly this conclusion is also valid for comparison III, which means that image quality does not have any impact on the point determination during the processing in PhotoModeler.

A remarkable conclusion is that in the PhotoModeler environment the creation of the 3D model of such a monument, using several pre-marked control points of known coordinates, is a very accurate method. The accuracy of the final product is comparable with the accuracy of the laser scanning point clouds

modeling, which is proved to be the most satisfactory one; deviations between these models are ≤2 cm in point coordinates or in distances (check II).
On the contrary, relative deviations are bigger when model 1 (from stereo-restitution in SSK) participates to the comparisons (checks I and IV). This conclusion can be clearly shown through the distance comparisons (ΔS), which give differences of 4.5-5 cm. However, these differences are totally in tune with the relevant coordinate deviations, as shown in Table 4. Distance differences for the other two comparisons (checks II and III) give small values of rms(ΔS), that is almost no difference in the scale between the compared models.

5. CONCLUSIONS

There is a variety of photogrammetric techniques that can produce raster products and 3D models for the geometric recording of monuments like a Byzantine church. The desired accuracy is at least of the scale of 1:100 and usually of 1:50 or even 1:25, while especially important is the quality of visualization and the possibility of detail representation of the monument. An evaluation attempt of such techniques includes the procedures described in this paper. Conventional photogrammetric procedures such as stereo-restitution and manual extraction of DSM for orthophoto production, but also the combination of those methods with 3D point clouds derived from terrestrial laser scanning were examined. Also the capabilities of photogrammetric software packages, such as PhotoModeler, for the direct extraction of 3D textured model were investigated. Several comparisons have been made concerning the quality of the products and their accuracy; absolute, systematic and relative errors of check point coordinates and distances were calculated. Comparisons concluded in especially interesting results.
Referring to field work: In order to achieve high accuracies, the use of pre-marked and geodetically measured control points or reflective targets (for laser scanning) is necessary even if they are not needed for a particular method. Laser scanning provides a huge amount of 3D data, its use though is not always easy, especially for the survey of large monuments; this is because scanning should be done from a higher level than the ground surface in order that a full coverage will be achieved. In such cases, use of digital images or videos is much easier and does not demand special precautions to avoid vibrations of the platform.
Referring to office work, a very important factor is automation in data processing and product extraction. The use of point clouds for modeling or, in combination with photogrammetric techniques, for orthoimage production, are typical examples. On the contrary, the use of PhotoModeler needs manual operation, which may give very good results considering accuracy and quality of the products, but is especially time consuming. However, the instrumentation cost and the user-friendly environment are the key parameters that increase the range of applications of this type of software.

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