INTEGRATION OF PHOTOGRAMMETRIC AND 3D LASER SCANNING DATA AS A FLEXIBLE AND EFFECTIVE APPROACH FOR HERITAGE DOCUMENTATION

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ABSTRACT:

The paper describes a variety of software solutions for photogrammetric and laser scanning data recording and integration purposes. The methodology for generating 2D, 2.5D, and 3D site documentation products is presented. The software and the sample products being described are the result of several years of work by a team of computer scientists and photogrammetrists. Being a software development and service company, we strive to discover technological solutions based on the ongoing needs of our production department and those of our customers. Every new documentation project is an opportunity to create new solutions or optimize existing ones.

Our technology is dedicated to the documentation of geometrically complicated sites and objects of different sizes where the products are interactive documentation and visualization packages. Our technological approach provides the ability to generate 3D visualizations without any geometrical and colour simplifications. Semi-automated processes for documentation and visualization purposes are available The software package presented herein includes a 2.5D orthophoto viewer – an easy-to-use mapping tool for architects, archeologists, art history investigators, curators, etc… The use of data integration processes constitutes a flexible solution applicable to most heritage site documentation projects.

1. INTRODUCTION

1.1 Documentation of Heritage Sites and Artifacts

The documentation of heritage sites and artifacts using advanced geocomputational technologies constitutes a growing sector of the market for mapping solutions. In addition to classic methods such as direct measurement and close range photogrammetry, cutting edge 3D laser scanning is quickly becoming one of the most commonly used techniques.

1.1.1 Measurement Objects: In practice, sites and artifacts that need to be documented come in different shapes and sizes. The authors of this paper have taken part in projects that involved small objects such as museum exhibits (porcelain figures, furniture, fabrics, even mummified remains in crypts) as well as large entities such as urban planning schemes (Boehler & Marbs, 2004). The authors have also worked with medium size sites and objects such as altars, chapels, churches, palaces, castles, fortresses, etc… This type of variety in terms of scale, unusually complicated geometry, as well as the need for faithful reproduction of complex color schemes (polychrome documentation) pose a serious challenge to any specialist attempting to properly document heritage sites and artifacts.

1.1.2 Customers: Individuals in charge of heritage sites and artifacts who make decisions regarding the creation of cartographic materials usually are not experts in the field of geodesy. In most cases, they are architects, archaeologists, curators, museum directors or administrators. In practice, it is often the case that a customer must not only be provided with a documentation product, but also the information technology tools that will allow him or her to make additional measurements and perform basic analyses using the data provided.

This is particularly important to individuals with an education not related to geodesy and those who are not well versed in technological issues and spatial relationships. The concept presented below is both useful and interesting and would be supplied to customers along with the main product.

1.1.3 Methods and products: In addition to measuring using a tape or a tachymeter, close range photogrammetry has been used for a number of years. However, with non-metric and semi-metric digital cameras becoming increasingly easier to use for photogrammetric purposes, the range of their possible uses in documentation processes has also expanded. Typically, photogrammetric documentation is created for architectural plans, 3-D models, and orthophotos.

In recent years, a new and more accurate and more efficient tool has come along which has proven itself to be highly effective in the recording of the geometry of heritage sites and artifacts, according to experts in the field (Balzani et al, 2002; Cantoni et al, 2002; Ioannidis & Tsakiri, 2003; Alshawabkeh et al, 2008). It is called 3D laser scanning and it has been used by the authors of this paper for a number of years in rather complex documentation processes. In addition to recording the shape of an object, this technique records the intensity of the reflected laser beam or color surface at a given point being studied. This technology constitutes a competing solution to photogrammetry with respect to measurement tasks associated with documentation work (Lichti et al, 2002; Guarnieri, 2004). It can also be used to generate architectural plans, 3D models, or

quasi-orthophotos – color or grayscale orthogonal views of point clouds which are the result of resampling, analogous to orthophotogrammetric products (Mavromanti et al, 2003).

1.2 Data Integration

The widespread use of both methods mentioned leads to the rational conclusion that photogrammetric and scanning data could be integrated to improve documentation technology (Georgopoulos et al, 2004). The integration of data is understood by the authors to be the use of data acquired using both technologies to generate a known product using this new and more efficient approach or a product that could not be generated without this type of integration (Rzonca, 2008).

1.2.1 Integration products: The products of data integration can be divided into two groups:

Photogrammetric products which have been created using additional data acquired by scanning processes. Almost every photogrammetric product can be generated using additional data acquired by scanning processes. For example, one product may be a scanning orthophoto – an orthophoto generated using an appropriately filtered point cloud as a numerical surface model. There is, of course, a wide variety of possible integration products: e.g. a vector diagram acquired using a digital photogrammetric workstation augmented by point cloud measurement results. In addition to 2D products, there exists a whole range of 3D products.

The second group consists of scanning technology products generated using data acquired using photogrammetric techniques. A basic product of integration in this case may be an orthogonal view of a color point cloud. This is the result of image resampling from a point cloud where each point has been assigned a color based on photogrammetric imagery. There is also a technique, analogous to photogrammetric technology, which allows the augmentation of point clouds and architectural diagrams (generated based on point clouds) with photogrammetric measurement data.

1.2.2 Guidelines and Options in the Use of Data Integration: General guidelines in the use of data integration are based on identifying an optimal technological solution and minimizing the amount of on-site and off-site work while maintaining a product's quality in terms of geometry and visual attributes as well. The "integrated" product must be of equal or superior value to the "non-integrated" product. The integration may take place during data acquisition (on-site integration) or during off-site work (off-site integration). On-site integration depends entirely on the equipment used (Bouroumand & Studnicka 2004; Buckley et al, 2006). This type of integration may, for example, involve the assignment of RGB components – recorded by a scanner's own camera – to scanned data points. Office integration, on the other hand, is possible thanks to the use of appropriate software and may take place at several stages of data processing:

The first stage is the absolute image and point cloud orientation stage. Off-site integration can take advantage of the use of data from one method for the absolute orientation of data from another method (Perfetti et al, 2005; D'Amelio et al, 2005). For example, a measurement made on a point cloud is used for the absolute orientation of images from a photogrammetric block. It is also possible to adjust an image block and a point cloud using the method of least squares.

The second stage consists of product generation. The orthorectification of images may be performed using point clouds (Georgopoulos et al, 2004; Agnello et al, 2005). By analogy, point clouds may be colored using RGB values obtained from an image (Stylianidis et al, 2005; Pyka & Rzonca, 2006).

The last stage is the stage where products derived from both methods are integrated. For example, a photogrammetrically derived vector may be superimposed on a view of a color point cloud (Hanke & Boehler, 2004; Guarnieri et al, 2006).

Data has to be properly prepared before it can be integrated. A test process constitutes a check of the quality of the preparation process.

1.3 The advantages and disadvantages of data integration

The use of integrated data offers a range of potential advantages. It allows for a flexible application of measurement technology to the customer's expectations, the specific nature of an object of analysis, and the particular conditions in which the measurement is being made. A proper application of integration processes eliminates the flaws associated with particular technologies being used alone. However, being a complex process, integration possesses its own set of serious flaws. Namely, there is the need to have two types of sensors as well as the skills to cohesively integrate spatial and image data acquired therefrom. However, it is worth noting that the use of appropriate algorithms can simplify and accelerate data integration processes.

2. RESEARCH WORK

2.1 Object and Project Description

Research work has been conducted based on data acquired as part of a major project led by the DEPHOS Ltd. and KPG Ltd. companies in the field of cultural heritage in Atturaif near Riyadh in Saudi Arabia. A 350-year old city, the cradle of the royal Saud family, was to be documented. The city is built of mud brick and stone. The project included all street-front façades of buildings, 21 palaces, mosques, and defense walls. A Z+F Imager 5003 scanner was used to acquire data from 2100 scanning positions. For research purposes, one cloud encompassing the façade of a palace that once belonged to Fahad bin Saud was selected. With data integration testing in mind, three additional photogrammetric images were generated using a Canon 5D camera with a 28mm lens.

The research described herein is based, in part, on data and documentation products generated as part of the doctoral dissertation of Antoni Rzonca.

2.2 Preparation of Integration Products.

DEPHOS software was used for data acquisition and processing both in the case of photogrammetric data as well as scanning data. The test surface of the previously mentioned Fahad bin Saud Palace façade was used to test data integration procedures. The data integration products obtained this way were the following: a scanning orthophoto, a view of a color point cloud,

and a 2.5D orthophoto. All of these products were generated using a photogram with a resolution of 4368 x 2912 pixels as well as a point cloud with a field resolution of 1mm (Figure 1). The absolute orientation of both data sets was performed based on the same control points marked on the façade whose coordinates were based on a system with the z-axis being perpendicular to the wall and turned towards the observer.

Figure 1. Middle photogram used to generate data integration products

The point cloud used to generate the aforementioned products was geometrically filtered before use with respect to its application to orthorectification as a numerical surface model. Special procedures were used to analyze relationships between points in the point cloud. For each given surface of an orthophoto, neighboring point analysis was performed for each point. A normal line was traced through each given point. A cylinder was defined around this line with a radius being noted. If a point was found within this cylinder of space, then its location with respect to the original point was investigated. If a point was found outside the defined cylinder, it was removed from the point cloud. If, one the other hand, a point was found inside the defined cylinder and close to the original point, then its location was shifted along the normal line. In this manner, "irrelevant" points were removed and the cloud smoothed out.

This type of preparation of the numerical model of the surface eliminated the most basic source of orthorectification process errors. In this way, the product (the scanning orthophoto) is of a quality comparable to that of the original image. Once every point within a filtered cloud is assigned a color using an algorithm which functions based on collinearity, the filtered cloud is used to resample an image from an orthogonal projection. The view of a color point cloud is a scanning product, analogous to a photogrammetric orthophoto (Figure 2). As had been mentioned earlier, the third product generated by data integration is a 2.5D orthophoto. It is an orthophoto where each pixel is assigned a distance from the projection plane.

A properly programmed viewer allows for the measurement of horizontal and slope distances as well as for the generation of automatic profiles along given line segments. Spatial measurements on a 2.5D orthophoto do not require stereoscopic observations (Figure 3) which makes it a lot easier to acquire information, especially when the user is not experienced in performing stereoscopic measurements, and increases the accuracy of the obtained information as well. In practice, the

use of 2.5D orthophotos also allows for the elimination of substantial costs which are associated with stereoscopic model measurements as well as point clouds. Such costs are derived from the purchase of specialized software: a digital photogrammetric workstation and cloud processing software.

The next section will present comparative analysis used to evaluate the quality of measurements performed on a 2.5D orthophoto.
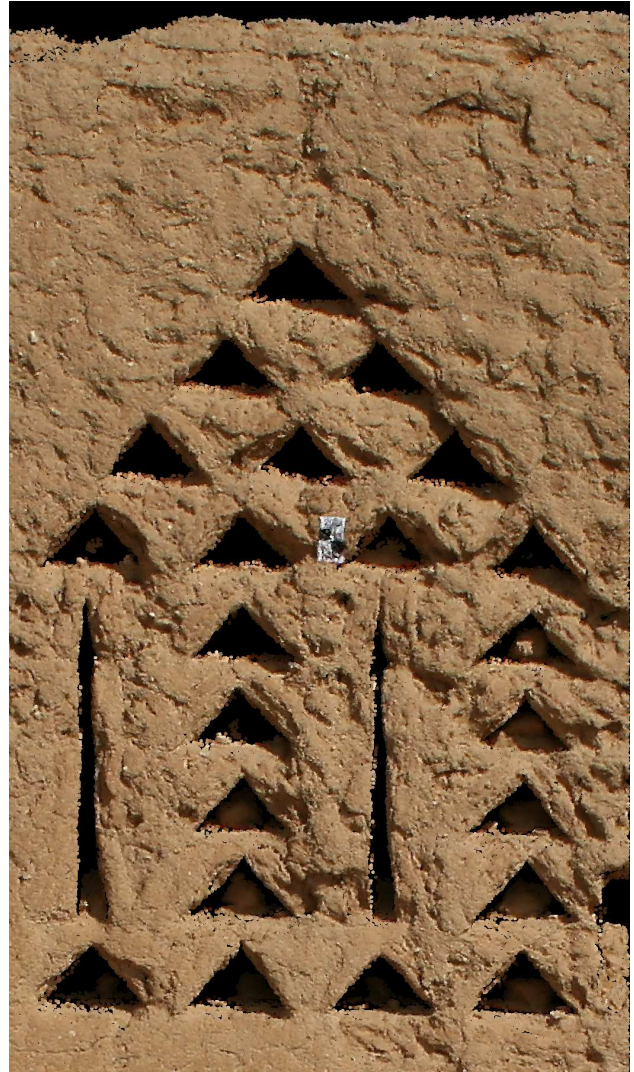

Figure 2. View of a color point cloud

3. TESTING THE 2.5D ORTHOPHOTO PRODUCT

3.1 Basic Analytical Assumptions

The purpose of the analysis presented herein is to define the reliability level of a tool designed to perform profile measurements on a 2.5D orthophoto. A comparison of the height of four types of profiles was necessary for this purpose:

- Type 1: profiles measured on a stereoscopic model;
- Type 2: profiles measured stereoscopically on a point cloud;

- Type 3: profiles measured on a point cloud along a profile;
- Type 4: profiles generated automatically on a 2.5D orthophoto given an assumed interval between height sampling points.

Each type has been tested using the DEPHOS system along the same four cross-sections of the façade of the Fahad bin Saud Palace: two of diagonal directions, one horizontal, and one vertical. The height over the surface of the 2.5D orthophoto was compared at each Type 4 profile height sampling point. Statistical calculations were performed on three groups of height differences computed at every height sampling point in all four profiles. Height differences were grouped in three different ways:

- Group A: the height measured in the Type 1 profile was subtracted from the height of the Type 4 profile height sampling point;
- Group B: the height measured in the Type 2 profile was subtracted from the height of the Type 4 profile height sampling point;
- Group C: the height measured in the Type 3 profile was subtracted from the height of the Type 4 profile height sampling point.
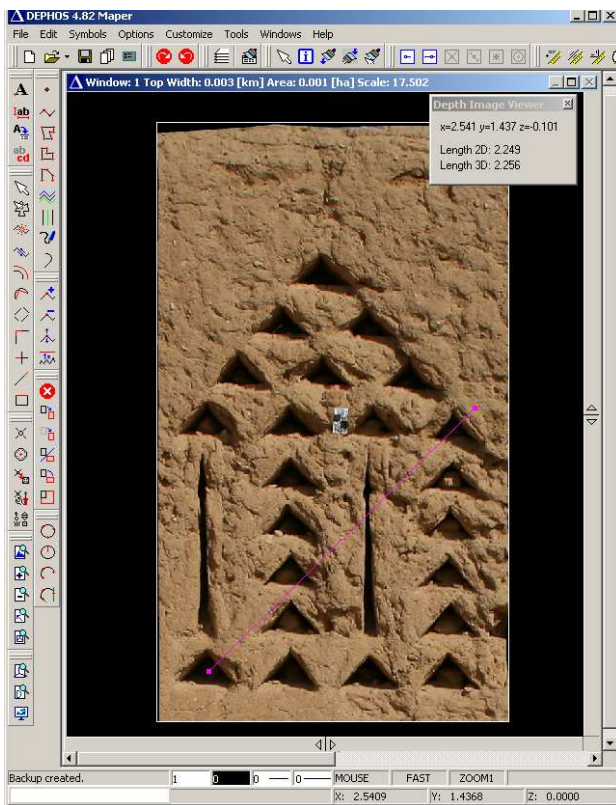

Figure 3. A 2.5D orthophoto with slope distance measurement

3.2 Acquiring Data for Analysis

Type 1 profiles were acquired manually based on a stereoscopic model using an additional dedicated function in the DEPHOS Mapper application. Initially, the operator would decide the path of the cross-section (saved as a vector file) placed against

the background of a stereo model. This function then would cut the selected path into segments with lengths (0.02m) selected by the operator and then it would position the measurement cursor at the starting point. The lengths of the profile paths were as follows: diagonal profile – 3.243m and 3.346m, surface cross-section profile – 1.926m, and surface length profile – 3.174m. Once an appropriate height has been recorded, the cursor would automatically jump to the next point. This type of partially-automated measurement technique allowed for faster data point acquisition at particular points in the profile. The results were saved as an ASCII file. Next, Type 2 profile points were analyzed along the same cross-section using the same function which creates consecutive ASCII files. The next acquired profile was a Type 4 profile. One of the basic functions of the DEPHOS Depth Image Viewer is the automatic height measurement of profiles at points with XY coordinates which correspond to Type 1 profile points in the given ASCII file. The Type 3 profile was acquired manually based on a measurement of the height component between the displayed point cloud cross-section and the imported Type 4 profile points.

3.3 Analysis results

The following statistical indicators were computed for differences between profile heights from 2.5D orthophotos and those from the three other products:

- mean difference
- standard deviation of a difference
- median difference
- maximum difference
- minimum difference

In addition, Pearson's coefficient of correlation between heights obtained from 2.5D orthophotos and heights obtained via direct 3D measurements was computed for Group A and Group B data. Also computed for these groups was R^2 – the coefficient of determination. The above listed parameters were not computed for Group C as height differences were measured directly in the case of the 2D profile without measuring profile point heights. Table 1 presents the values of particular indicators for each investigated profile.

It is important to note that when a product involves the use of a point cloud, there is practically total agreement between measured height values and height values obtained automatically from 2.5D orthophotos. This is consistent with the authors' expectations as the basis for the creation of a 2.5D orthophoto is a numerical surface model generated from the same point cloud. The value of R^2 is close to unity for heights which had been used as bases for the calculation of differences in Group B. This means that there exists a linear relationship between measurements. The above mentioned fact as well as the near-zero values of basic statistical parameters (the mean and the median of differences) indicate virtually total agreement between the measured results. Furthermore, standard deviation values, which in this case correspond to the working accuracy of the operator of a digital photogrammetric workstation, lead to the conclusion that the processing of point clouds for the purpose of obtaining numerical surface models does not have a meaningful effect on the accuracy of obtained results.

Maximum and minimum values of height differences can reach 3cm. and are produced by the presence of "irrelevant" points

within point clouds – points that had not been removed during point cloud filtering.

When considering the photogrammetric measurement values on the stereogram, one can conclude based on the mean and median height difference values that an adjustment error (approx. 1cm. along the z-axis) must have occurred during the photo and point cloud orientation process. This is further confirmed by the values of maximum and minimum height differences – most of which are positive.

		Cross-section 1 (diagonal)		
		Group A	Group B	Group C
Mean	[m]	0,0098	0,0003	-0,0004
Standard dev.	[m]	0,0065	0,0023	0,0032
Median	[m]	0,0087	0,0003	0,0000
V-max	[m]	0,032	0,009	0,004
V-min	[m]	-0,004	-0,008	-0,030
Correlation (R)	-	0,9953	0,9994	---
R^2	-	0,9906	0,9988	---
		Cross-section 2 (diagonal)		
		Group A	Group B	Group C
Mean	[m]	0,0120	0,0000	0,0003
Standard dev.	[m]	0,0065	0,0037	0,0024
Median	[m]	0,0116	-0,0002	0,0000
V-max	[m]	0,039	0,021	0,021
V-min	[m]	-0,007	-0,008	-0,006
Correlation (R)	-	0,9855	0,9955	---
R^2	-	0,9711	0,9910	---
		Cross-section 3 (horizontal)		
		Group A	Group B	Group C
Mean	[m]	0,0103	-0,0001	0,0000
Standard dev.	[m]	0,0074	0,0026	0,0014
Median	[m]	0,0113	0,0000	0,0000
V-max	[m]	0,030	0,006	0,005
V-min	[m]	-0,008	-0,013	-0,005
Correlation (R)	-	0,9691	0,9957	---
R^2	-	0,9392	0,9915	---
		Cross-section 4 (vertical)		
		Group A	Group B	Group C
Mean	[m]	0,0119	0,0001	0,0001
Standard dev.	[m]	0,0082	0,0034	0,0034
Median	[m]	0,0117	0,0001	0,0001
V-max	[m]	0,038	0,011	0,011
V-min	[m]	-0,007	-0,015	-0,015
Correlation (R)	-	0,9909	0,9983	---
R^2	-	0,9818	0,9966	---

Table 1. Comparison of statistical indicators computed for 4 cross-sections.

Higher standard deviation values for height differences are the result of electronic noise which tends to plague point clouds. Noise is a physical characteristic inherent of the measurement technology used in 3D laser scanners (phase measurement, impulse measurement) and it cannot be fully eliminated in the data filtering process. It is estimated that, as in the case of point cloud measurements, operator error in the process of stereogram measurement is +/- 3mm. Based on this estimate, it can be inferred that in the case of this particular scanner (Z+F Image 5003), noise can lower the accuracy of an acquired profile 2 to 2.5 times compared to the accuracy obtained using the photogrammetric method.

This is confirmed by the lower value of R^2 for Group A data which indicates that variability in the photogrammetrically acquired profile does not fully explain the variability in the profile acquired using a 2.5D orthophoto.

4. CONCLUSIONS

The above listed results lead to the conclusion that a 2.5D orthophoto is a valuable data integration product and can serve, in conjunction with appropriate tools, to produce measurements (of e.g. heritage sites) for documentation purposes. Having such as measurement solution at hand may be especially valuable to individuals with little or no experience in stereoscopic measurements. The authors of this paper have attempted to show that an individual in possession of a 2.5D orthophoto and appropriate software is able to automatically acquire any desired cross-section of an object with accuracy comparable to that of measurements made by an experienced observer working with a point cloud in 3D or 2D or in cross-section. The advantage of using 2.5D orthophotos in photogrammetric production also stems from the fact that potential customers are more likely to choose certain forms of documentation if they know that they are taking full advantage of the product they have selected.

In conclusion, it is important to note that besides making sample slope distances measurements and generating automatic profiles, there is a variety of other 2.5D orthophoto measurement possibilities. They include profiles along polylines, surface areas within enclosed shapes taking elevation differences into account, solid volumes above assigned height levels, and spatial vector measurements based on "monoplotting".

REFERENCES

Agnello F., Lo Brutto M., Lo Meo G., 2005, DSM and Digital Orthophotos in Cultural Heritage Documentation. In: Proc. CIPA XX International Symposium, Torino, Italy.

Alshawabkeh Y., Haala N., Fritsch D., 2008, Range Image Segmentation Using the Numerical Description of the Mean Curvature Values. In: *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. Beijing, China, Vol. XXXVII, Part B5, pp. 533-538.

Lichti D. D., Gordon S. J., Steward M. P., Franke J., Tsakiri M., 2002, Comparision of Digital Photogrammetry and Laser Scanning. In: Proc. CIPA-ISPRS Workshop on Scanning for Cultural Heritage Recording, Korfu, Greece, pp. 27-32.

Boehler W., Marbs A., 2004, 3D Scanning and Photogrammetry for Heritage Recording: a Comparision. In: Proc. 12th Int. Conf. of Geoinformatics, Gavle, Sweden.

Bouroumand M., Studnicka N., 2004, The Fusion of Laser Scanning and Close Range Photogrammetry in Bam Laser-Photogrammetric Mapping of Bam Citadel (Arg-e-Bam)/Iran. In: *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Istambul, Turkey, Vol. XXXV, Part B5.

Buckley S.J., Howell J.A., Enge H.D., Leren B.L.S., Kurz T.H., 2006, Integration of Terrestrial Laser Scanning, Digital Photogrammetry and Geostatical Methods for High-Resolution Modelling of Geological Outcrops. In: *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Dresden, Germany, Vol. XXXVI, Part B.

Cantoni R., Vassena G., Lanzi C., 2002, Laser Scanning and Traditional Survey Integration to Build a Complete 3D Digital Model of "Sagrestia dell'Archivo di Stato a Mantova". In: Proc. CIPA-ISPRS Workshop on Scanning for Cultural Heritage Recording, Korfu, Greece, pp. 105-114.

D'Amelio S., Emmolo D., Lo Brutto M., Orlando P., Villa B., 2005, 3D Techniques for the Survey of Cultural Heritages. In: Proc. CIPA XX International Symposium, Torino, Italy.

Georgopoulos A., Tsakiri M., Ioannidis C., Kakli A., 2004, Large Scale Orthophotography Using DTM from Terrestrial Laser Scanning. In: *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Istambul, Turkey, Vol. XXXV, Part B5, pp. 467-472.

Guarnieri A., Remondino F.,Vettore A., 2006, Digital Photogrammetry and TLS Data Fusion Applied to Cultural Heritage 3D Modelling, In: *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Dresden, Germany, Vol. XXXVI, Part B.

Guarnieri A., Vettore A., Remondino I. and F., 2004, Photogrammetry and Ground-based Laser Scanning: Assessment of Metric Accuracy of the 3D Model of Pozzoveggiani Church. In: Proc. FIG Working Week, Athens, Greece.

Hanke K., Boehler W., 2004, Recording and Visualisation of the Cenotaph of German Emperor Maximilian I, In: *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Istambul, Turkey, Vol. XXXV, Part B5.

Ioannidis Ch., Tsakiri M., 2003, Laser Scanning and Photogrammetry for the Documentation of a Large Statue - Experiences in the Combined Use. In: Proc. XIXth CIPA Symposium, Antalya, Turkey.

Lichti D. D., Gordon S. J., Steward M. P., Franke J., Tsakiri M., 2002, Comparision of Digital Photogrammetry and Laser Scanning. In: Proc. CIPA-ISPRS Workshop on Scanning for Cultural Heritage Recording, Korfu, Greece, pp. 39-44.

Mavromati D., Petsa E., Karras G. E., 2003, Experiences in Photogrammetric Archeological Recording. In: Proc. XIXth CIPA Symposium Antalya, Turkey.

Perfetti N., Pellegrinelli A., D'Urso M. G., Russo P., 2005, A Combined System of Digital Photogrammetry and 3D Laser Scanning. In: Proc. CIPA XX International Symposium, Torino, Italy.

Pyka K., Rzonca A., 2006, *Badanie jakości radiometrycznej ortofotogramów sporządzonych na drodze integracji fotogrametrii biskiego zasięgu i skaningu*. Investigation on the Radiometric Quality of Orthophotograms Generated by Integration of Close-Range Photogrammetry and Laser Scanning. In: *Archiwum Fotogrametrii, Kartografii i Teledetekcji*, Olsztyn, Poland, Vol. 16.

Rzonca A., 2008, *Integracja danych pozyskiwanych metodami fotogrametrycznymi i skanowania laserowego przy inwentaryzacji obiektów zabytkowych*. Photogrammetric and Laser Scanning Data Integration for Inventory of Monuments. In: unpublicized doctoral dissertation materials, Krakow, Poland.

Stylianidis E., Patias P., Liapakis C., Balis V., Philotheou G., 2005, Visualization of Frescos by Means of Photogrammetry and Laser Scanning. In: Proc. CIPA XX International Symposium, Torino, Italy.