

APPLICATION OF FISHEYE LENS AND TERRESTRIAL LASER SCANNING IN ARCHITECTONIC DOCUMENTATION OF HARD-TO-REACH CULTURAL HERITAGE OBJECTS

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ABSTRACT

In hard-to-reach places, (for example narrow streets or big buildings, located close to each other) creation of orthoimage and vectorial sketch using camera with classical lens is very difficult or sometimes impossible. In such situations we can combine photos from digital camera with three-dimensional model derived from Terrestrial Laser Scanning (TLS). Architectonic documentation is created on the basis of three-dimensional models and orthoimages. It is important product for architects or conservators in reconstruction of sculptures, monuments or inner and outer building facades. Both terrestrial laser scanner and fisheye lens have a very wide field of view. For this reason, thanks to combining those two techniques we can texture very precise models of vaults or facades, and we can detect and assess the size of damages or fractures in hard-to-reach places. In experiment, we assessed the use of 3D models derived from laser scanning, and images from digital camera with fisheye lens in making inventory and assessing the condition of vaulting, walls, sculptures etc.

All researches were made in the church and one of old buildings in the Old Town in Warsaw. We have examined shape and structure of walls, sculptures, paintings and polychromes. In publication we will present rules and results of registration process and integration of the TLS data with the images acquired with the digital camera Kodak DCS 14n Pro with the fisheye lens ($f = 10.5$ mm).

INTRODUCTION

In hard-to-reach places, (for example narrow streets or big buildings, located close to each other) creation of orthoimage and vectorial sketch using camera with classical lens is very difficult or sometimes impossible. Fisheye lenses provide imaging of large areas of the surrounding space by a single photo, sometimes more than 180 degrees. They enable to realize photos at very small distances, what in some elaborate engineering aspects may be particularly useful. In such situations we can combine photos from digital camera with three-dimensional model derived from terrestrial laser scanning. The most common application of terrestrial laser scanning and camera with the fisheye lens is architectonic documentation and inventory of cultural heritage objects. Vectorial sketches, façade models and formed on the basis of TLS models are frequently used by architects and monuments conservators. In most cases they serve as a documentation indispensable to reconstruction of actual state of the objects before renovation. Terrestrial Laser Scanning as a very precise instrument is perfect to these purposes. Except 3D models and sketches very important is also condition of the monuments (assessing their damages, crevices etc.). It is very important information, especially when we want to recreate a real and accurate condition of the object before its renovation, or if we want to generate orthophotos or very precise cross-sections.

In Poland, technical instruction G-3.4 comprises the rules of completing architectural documentation. It provides information about all requirements that are needed in projects concerning cultural heritage security.

In the paper we present some analysis of architectural inventory aspects and condition of the one of the churches in Warsaw.

DATA COLLECTION

Images were taken with the Kodak DCS 14n Pro digital camera ($f=10.5\text{mm}$) with the matrix 4500×3000 pixels. Point cloud data was acquired by Leica ScanStation2 – one of the Leica Geosystems HDS product family. It is a universal pulsed laser scanner with a high range (300 m). High productivity of ScanStation2 is assured by high accuracy of single point position determination (6 mm), precise distance measurement (4 mm), and above all – unusual ability of sampling density below 1 mm. Such approach is useful especially in measurements of very small architectonic or industrial elements. Scanner optic consists of single mirror, leading laser beam on its input and output. Laser spot obtains size from 4 to 6 mm in the distance of 0-50 m. System can acquire even 50 000 points per second. Range of scanner is up to 300 m (90 % albedo) and 134 m (18% albedo). Instrument has also wide field-of-view ($360^\circ \times 270^\circ$), and by the long distances it allows scanning of hard-to-reach places, for example: tunnels, bridges, high buildings, columns, towers or very wide areas. Scanner computes point position, by measuring time-of-flight of laser beam on particular distance, determination of direction to this object and finally transforming data in specified coordinate system.

Figure 1 depicts the result of the scanning of the façade. Scanning resolution was established as 0.007 m. All scans, from particular stations were recorded as point clouds in separate Scan Worlds.

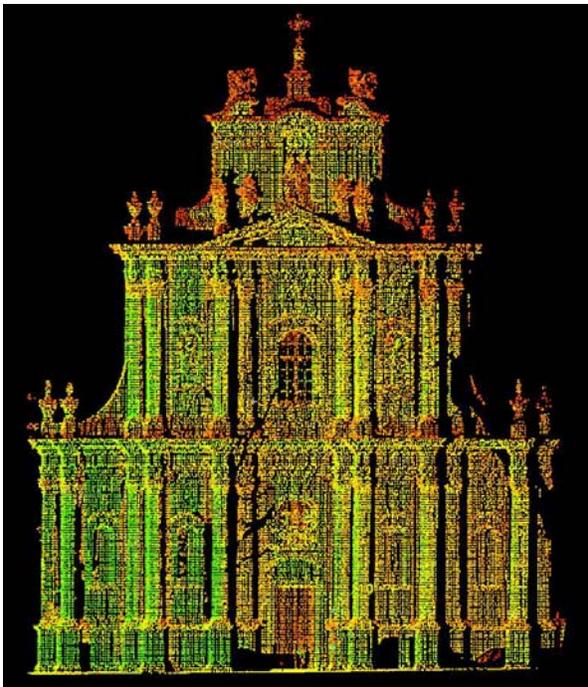


Figure 1. Church façade – degraded scan.



Figure 2. Façade in the image acquired by the digital camera with the fisheye lens.

Measurements were made from three stations, in order to scanning of all façade elements. Positions of stations were dependent on the façade exposure, partially hidden by trees or cars.

Because of high objects and columns, images taken with the camera with the classical lens (for example 24 mm) could not be done. The church is partially hidden by the trees, what is visible in the figure 1. Only photos, taken with the fisheye lens camera can overlap the whole building façade with the one image from very short distance (even 2 m), what is shown in the figure 2.

Registration

After scanning, all scans from different Scan Worlds have to be merged and oriented. Relative orientation and fitting of scans, acquired from independent stations is called scan registration. Registration can be done by the *point cloud registration* method – it is manual choosing of the corresponding details and points in two or more scans, or fully automatically – by searching known homologous points (HDS targets) and by searching geometric features –

contours or patches. C. Brenner and C. Dold proposed algorithm of scan relative orientation: first patches are automatically searched and then triples of them from different data sets are being assigned to each other. It serves determination of relative orientation components: rotation and shifts between all point clouds that compose object scan. Six degrees of freedom are determined mathematically. First, rotation matrix R is found using eigenvectors analysis and then, translation vector t have to be determined. Any two corresponding points are related by an Euclidean (rigid) transformation:

$$x_1 = R \cdot x_2 + t \quad (1)$$

Vector t is found, using approach which relies on planar patches. After some conversions, we obtain vector t from equation:

$$\begin{bmatrix} n^T \\ m^T \\ p^T \end{bmatrix} \cdot t = \begin{bmatrix} d_1 - d_2 \\ e_1 - e_2 \\ f_1 - f_2 \end{bmatrix} \quad (2)$$

where n, m, p are normal vectors of plane.

Such approach assures uniform distribution of angle determination error.

For fitting of the scans we used 5 HDS targets located in visible from all stations places. Very precise determination of their spatial position is possible, because the centers of the targets reflect light strongly. The mean error of the automatic registration process was equal 0.004 m. Registration accuracy is presented by the error in the fourth column of the table 1. Errors in the horizontal and vertical directions and errors on particular points shows columns fifth, sixth and seventh (error vector, and in horizontal and vertical direction):

Table 1. Scan registration report

Name	ScanWorld	ScanWorld	Error [m]	Error Vector [m]	Horz [m]	Vert [m]
TargetID: 10	ScanWorld 1	ScanWorld 2	0.002	(-0.001, -0.001, -0.001)	0.001	-0.001
TargetID: 12	ScanWorld 1	ScanWorld 2	0.001	(-0.001, -0.001, -0.000)	0.001	0.000
TargetID: 14	ScanWorld 1	ScanWorld 2	0.002	(0.002, -0.001, -0.000)	0.002	0.000
TargetID: 10	ScanWorld 1	ScanWorld 3	0.003	(0.001, -0.003, -0.001)	0.003	0.001
TargetID: 12	ScanWorld 1	ScanWorld 3	0.008	(-0.006, 0.005, 0.000)	0.008	0.000
TargetID: 14	ScanWorld 1	ScanWorld 3	0.005	(0.005, -0.002, 0.000)	0.005	0.000
TargetID: 14	ScanWorld 2	ScanWorld 3	0.004	(0.003, -0.003, 0.000)	0.004	0.000
TargetID: 12	ScanWorld 2	ScanWorld 3	0.007	(-0.005, 0.004, 0.000)	0.007	0.000
TargetID: 10	ScanWorld 2	ScanWorld 3	0.003	(0.001, -0.002, 0.002)	0.002	0.002
TargetID: 11	ScanWorld 2	ScanWorld 3	0.004	(0.002, 0.001, -0.003)	0.002	-0.003

From analysis of the results we assessed, that accuracy of vectorial handling of church façade using data from terrestrial laser scanning system can be done with an error of 0.005 m. In case of this sacral object, relative error is about 1: 6000. In order to reliable error assessment, at least 5 uniformly located targets (minimum is 3) should be used during scanning.

CONDITION OF THE OBJECT

The most important (in architectonic meaning) elements in the church are the exterior façade elements: columns, figures – sculptures etc., and interior elements: main vaulting, walls, altars, organs and ambo.

We have paid attention not only on spatial model or image of the church façade, but first of all on scanner precision analysis and usefulness of high point density in places of bursts or cracks.

Figure 3 a shows both: laser scanning point cloud and imaged fragment of the external column damage. Figure 3 b presents the same damage, but spatially modeled.

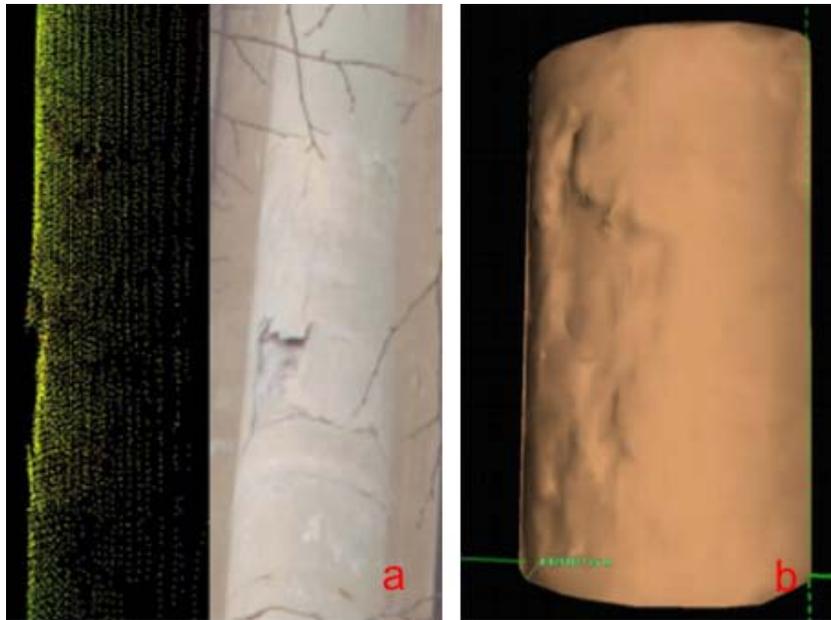


Figure 3. Damage of column: scan and image (a) and its model (b).

The size of this damage was measured and equaled $1348,50 \text{ cm}^3$.

High measurement precision of Leica ScanStation2 is indispensable also for little fracture or crevice detection. In neuralgic places, we made the scanning with the point spacing smaller than 1 mm. This solution was useful in measuring of very small architectonic single defects or bursts in hard-to-rich places. The view of the fracture run is shown in the figure 4 b.

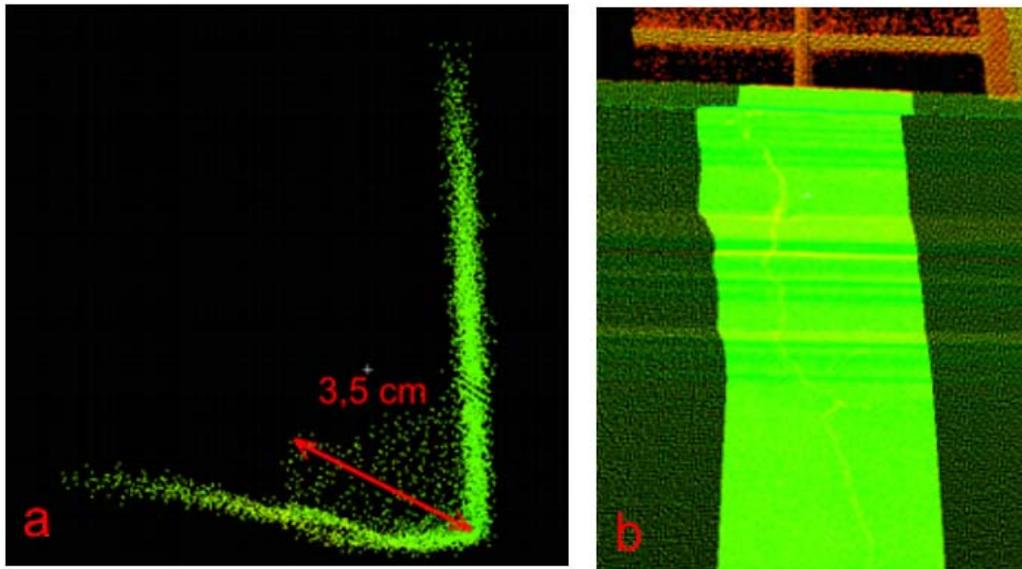


Figure 4. Fragment of crack section (a) and visualization of crack with point spacing lower than 1 mm (b).

Using this ability and making sections, we can estimate depth of such a crack (figure 4 a). By our investigations, we noticed, that the depth of the gaps with the width lower than 2 mm cannot be detected. Below this value (because of scanner possibilities) cracks measurements and detection are limited.

Texturing and Orthoimages

Another application of the digital camera with the fisheye lens and terrestrial laser scanning is making an orthophoto and precise measurements of the vaulting. Point cloud can be textured, using images from external or internal scanner cameras. We have made an comparison of those two approaches.

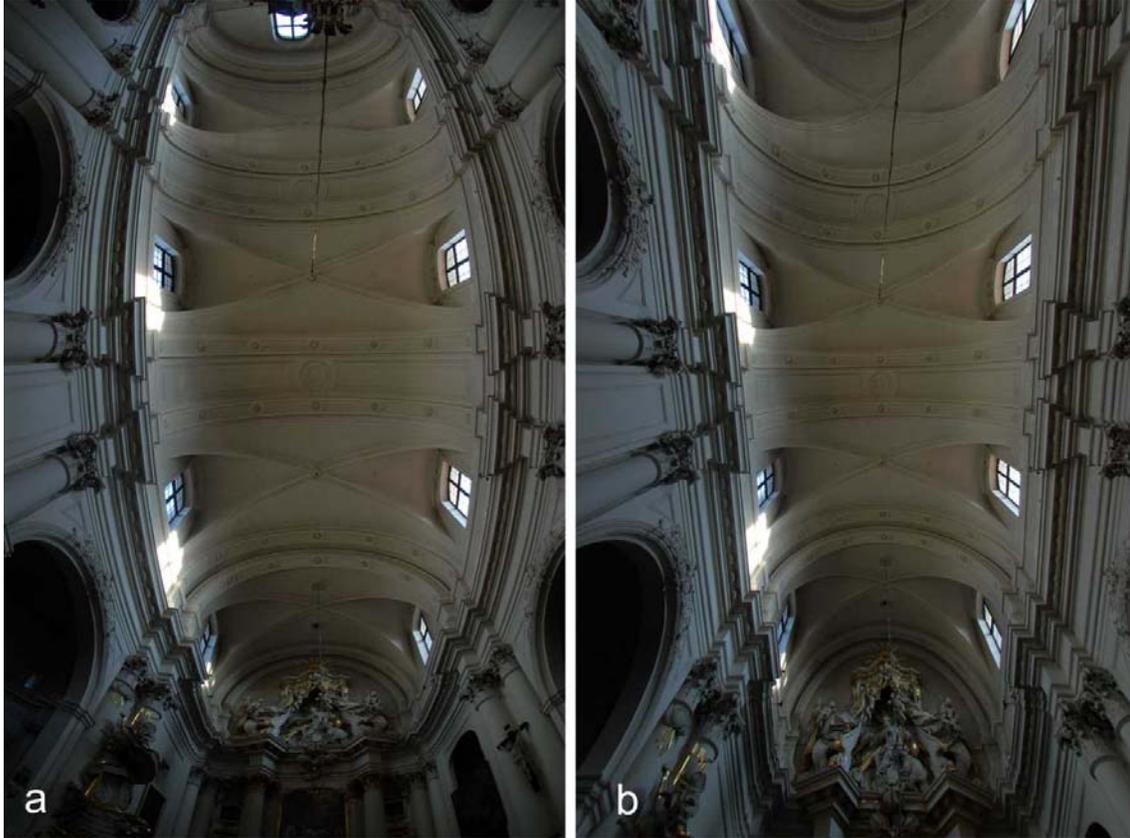


Figure 5. The image from fisheye lens camera. a – raw image, b – image after correction.

Figure 5 presents the vaulting. The same vaulting, but as a textured point cloud can be seen in the figure 6. Of course images taken with the camera with the fisheye lens have to be corrected due to very big fisheye lens distortion (figure 5 a). Precise description of the distortion determination and creating orthophoto can be found in our previous publications [Kedzierski, Fryskowska 2008, Kedzierski, Walczykowski, 2008].

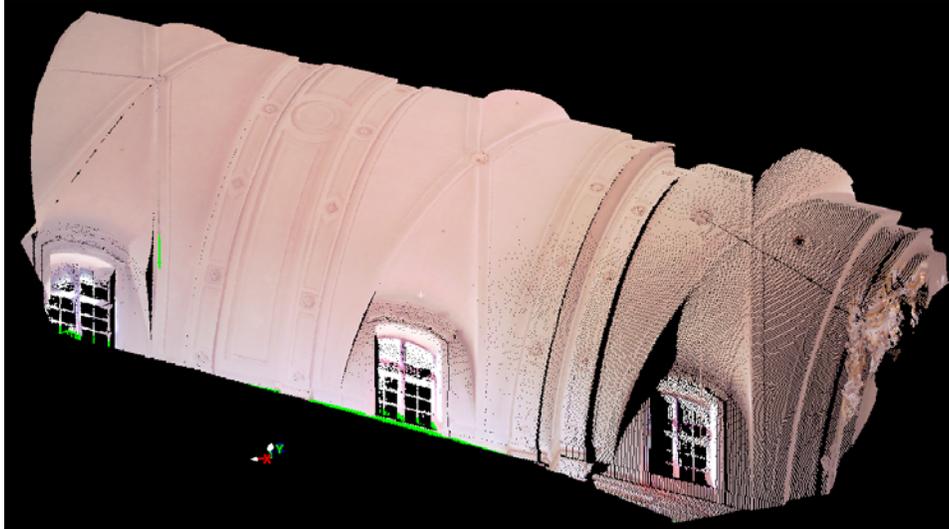


Figure 6. View of the ceiling with the image texture.

The main difference between photo and data from TLS is that the second one is a fully metric information. digital camera images have to be post-processed and transformed in a 3D model. Furthermore, “traditional” photogrammetry realizes measurement in a passive way, where external lightening is necessary. But on the other hand, it gives very important information about object color or topology.

Making an orthophoto requires transformation and connection of two different data types: point clouds and images. Such an integration can be done in two ways: laser data to image (ortho generation) or image to laser data (making realistic grids using point clouds and assigned to them pixel colors).

For transformation and integration of the point cloud 3D model with the image we used 7 corresponding points on both data sets. Accuracy of this process is defined by mean error of fitting, and in this case equaled 0.84 pixels. Integration data is useful especially in documentation, when frescos have to be presented as well.

Another Applications of TLS and Camera with the Fisheye Lens

The most crucial information for architects or conservators is three-dimensional visualization, geometry and a condition of the object. Pulsed Terrestrial Laser Scanner can measure even up to 50 000 points per second.

In opposition to the phase-scanners, pulsed laser scanners can recognize and measure polychromic painting frames or organs. They enable damage assessment and are the basic material in documentation.

Figure 8 presents a visualization of the fragment of the monument of the Chopin (in Warsaw). The whole object was scanned into 5 mln points.



Figure 7. Organs - an intensity image from scanner.

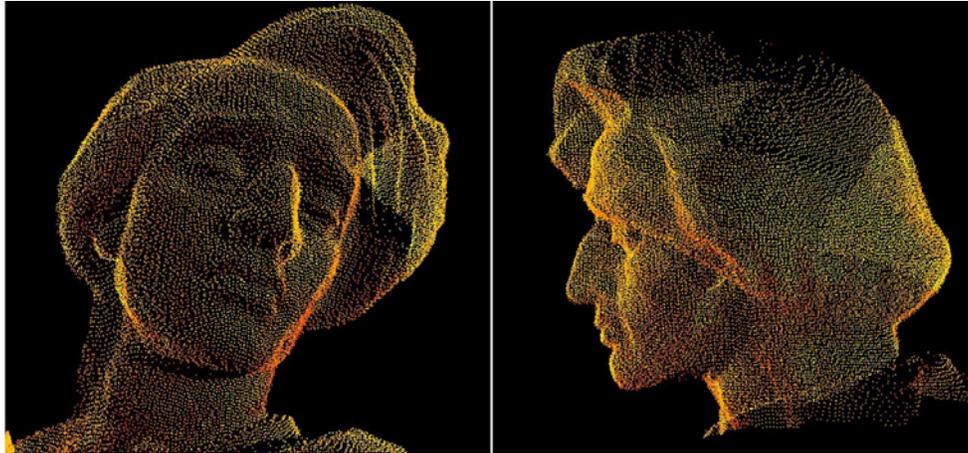


Figure 8. The view of several thousands of points of the scanned Chopin's face.

Both: digital camera with the fisheye lens and scanner have the same disadvantage – shadows. In the figures: 1, 2, 7 and 8 we can see all those shadows and losses of information. It is caused by complexity of the façade and monument, their shapes, and size.

CONCLUSIONS

Terrestrial Laser Scanning and digital cameras with the fisheye lens are one of the best tools for making inventory or architectonic documentation of hard-to-reach cultural heritage objects. In the most cases they give very important information, especially when we want to recreate a real and accurate condition of the object before its renovation, or if we want to generate orthophotos or very precise cross-sections. We made an attempt of assessment of scanner possibilities not only in 3D model generation and visualization but also in determination of usability of such measurements in renovation works. TLS data and orthophoto are accurate enough and can be used in examinations of damages of cultural heritage objects regarding shape or structure much faster than using another technologies.

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