changes, as well as spatial or spectral filtering, the module allows you to display only those changes that interest us.

Processing and analyzing data in IMAGINE DeltaCue are organized in the form of projects that provide a certain sequence of actions: preprocessing; detect changes; filtering detected changes; display and analysis of changes.

According to research data, the total surface area of flooding in Texas is 42% and Florida 37%.

Keywords: *Space Image, DeltaCue, Difference Indicators, Spatial Filtration, Hurricane Impact Assessment.*

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V. Seredovich, *Professor,*
Director of the Siberian Centre for Laser Scanning in Civil Engineering
Novosibirsk State University of Architecture and Civil Engineering (Sibstrin)
I. Kamnev, *PhD student*
Siberian State University of Geosystems and Technologies (SSUGT)

ANALYSIS OF THE THREE-DIMENSIONAL VECTOR FAÇADE MODEL CREATED FROM PHOTOGRAMMETRIC DATA

The results of the accuracy assessment analysis for creation of a three-dimensional vector model of building façade are described. In the framework of the analysis, analytical comparison of three-dimensional vector façade models created by photogrammetric and terrestrial laser scanning data has been done. The three-dimensional model built from TLS point clouds was taken as the reference one. In the course of the experiment, the three-dimensional model to be analyzed was superimposed on the reference one, the coordinates were measured and deviations between the same model points were determined. The accuracy estimation of the three-dimensional model obtained by using non-metric digital camera images was carried out. Identified façade surface areas with the maximum deviations were revealed.

Key words: *terrestrial laser scanning, ground-based photogrammetry, accuracy estimation, non-metric digital cameras, three-dimensional model.*

Technology modernization of cameras has led to a significant increase in the image resolution. The improvement of the digital image quality and the increase in personal computer performance make possible to use images taken by non-metric digital cameras for measuring purposes. It should be mentioned that the application of these cameras increase the efficiency of field geodetic works while making photography/surveying building façades without complex decorative elements. [3, 2]

The results of accuracy assessment analysis for creation of a three-dimensional building façade vector model are described. In the framework of the analysis, an analytical comparison of three-dimensional vector façade models created by photogrammetric and terrestrial laser scanning data was done.

To achieve this goal, we have made surveying of the main building of the Novosibirsk State University of Architecture and Civil Engineering using terrestrial laser scanning (TLS) and ground-based photogrammetry.

Terrestrial laser scanning technology is widely used in geospatial solutions for construction, reconstruction of buildings and structures [4, 8-9]. It allows determining the three-dimensional coordinates of the object under investigation with an accuracy of 1.5 mm and worse [4-5].

At the first stage, terrestrial laser scanning was applied for surveying of building façade from the only one scanner station. The measurements were performed by Riegl VZ-400 laser scanner during the night, cloudy and calm weather. This has made it possible to minimize the influence of refraction and vibrations of the scanner. The maximum distance from the scanner to the building façade was 30 m.

At the second stage, ground-based photography of the façade was carried out by Sony DSC-H50 - a digital non-metric camera. It was done according to a preliminary designed work schedule, which included both route and block surveying. A special attention was paid to the necessary number of overlaps between the digital images, as well as to minimize the "dead zones". To improve the quality result of surveying, all the works were carried out during day-time and in cloudy weather at a maximum distance of 33 m from the camera to the façade. Totally 84 digital images were taken covering an area of 809 m^2.

Digital camera specification is given in Tab. 1.

Table 1

Specification: Sony DSC-H50 digital non-metric camera

Parameter	Value
Resolution	3459x2592 pixels
Focus distance	5.2 mm
Aperture range	f/2,7 mm
ISO* sensitivity	80
Exposure	1/400 sec
*ISO - International Standardization Organization	

Camera calibration was made for the further determination of camera's elements of internal orientation elements in digital image processing.

For analysis purposes the conventional Cartesian coordinate system was adopted for a façade. In a given system, the X-axis is directed to the zenith (towards the roof), and the Y-axis to the east (along the building). Thus, the Z-axis is turned perpendicular to the façade, which was considered as a height. Therefore, the building façade seems to be laid on the earth surface. A digital façade model graduated in height and in a given coordinate system is shown in Fig. 1.

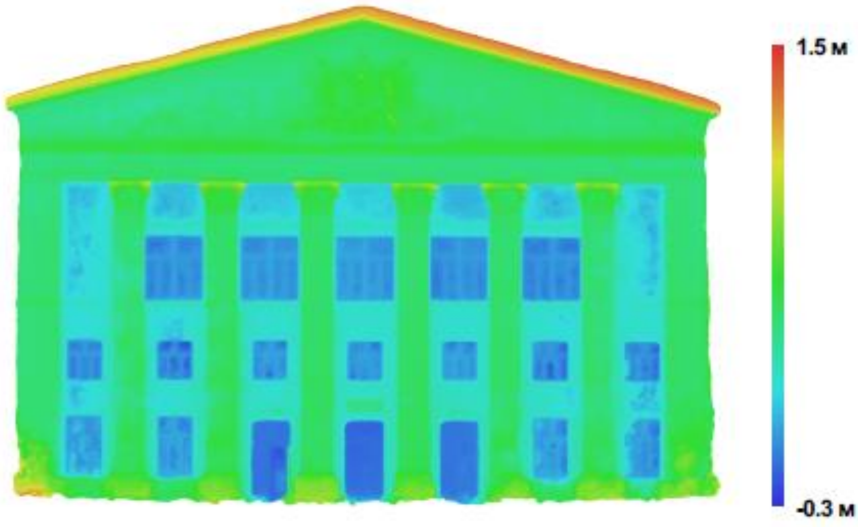

Figure 1: A digital façade model graduated in height

To define a conditional coordinate system, 21 control points are fixed on the façade. Their coordinates are measured by a point cloud of laser reflections (scans) and assigned to the corresponding points on digital images. Position errors of control points on images are given in Tab. 2.

Table 2

Position errors of control points on images

Point number	X (m)	Y (m)	Z (m)	S (m)	Projections
1	0.003	0.013	-0.005	0.014	26
2	0.013	0.014	-0.0001	0.030	19
3	0.009	0.007	-0.0002	0.019	27
4	-0.003	0.012	0.005	0.011	26
5	-0.008	-0.003	0.005	0.014	14
6	-0.004	-0.011	0.0002	0.010	20
7	0.013	-0.003	-0.001	0.012	32
8	0.007	-0.030	-0.006	0.013	26
9	-0.0004	-0.006	0.002	0.034	19
10	0.019	0.004	0.002	0.007	22
11	0.013	-0.001	0.002	0.019	19
12	0.008	0.010	-0.003	0.013	22
13	0.009	0.007	0.003	0.008	20
14	-0.022	-0.005	0.006	0.013	19
15	-0.018	0.024	-0.002	0.012	17
16	-0.005	0.006	0.001	0.023	24
17	0.001	-0.018	-0.003	0.018	19
18	-0.011	-0.007	0.007	0.015	23
19	-0.014	-0.0002	-0.004	0.014	17
20	-0.006	-0.004	-0.002	0.008	21
21	0.0003	-0.007	-0.006	0.009	20
RMS error (m)	0.011	0.012	0.004	0.016	

According to Tab. 2, it can be seen that the root-mean-square error (RMS error) of the position of control points on Z-axis is less than half a millimeter. The projection parameter characterizes the number of images on which a particular point is displayed. The error ‘S’ in Tab. 2 means the RMS error of determining the spatial position of the corresponding control point.

Processing of non-metric digital camera images was carried out in the office by Agisoft PhotoScan software. As a result, a three-dimensional façade models (point and vector models) were created from point clouds and images (Fig. 2, 3).

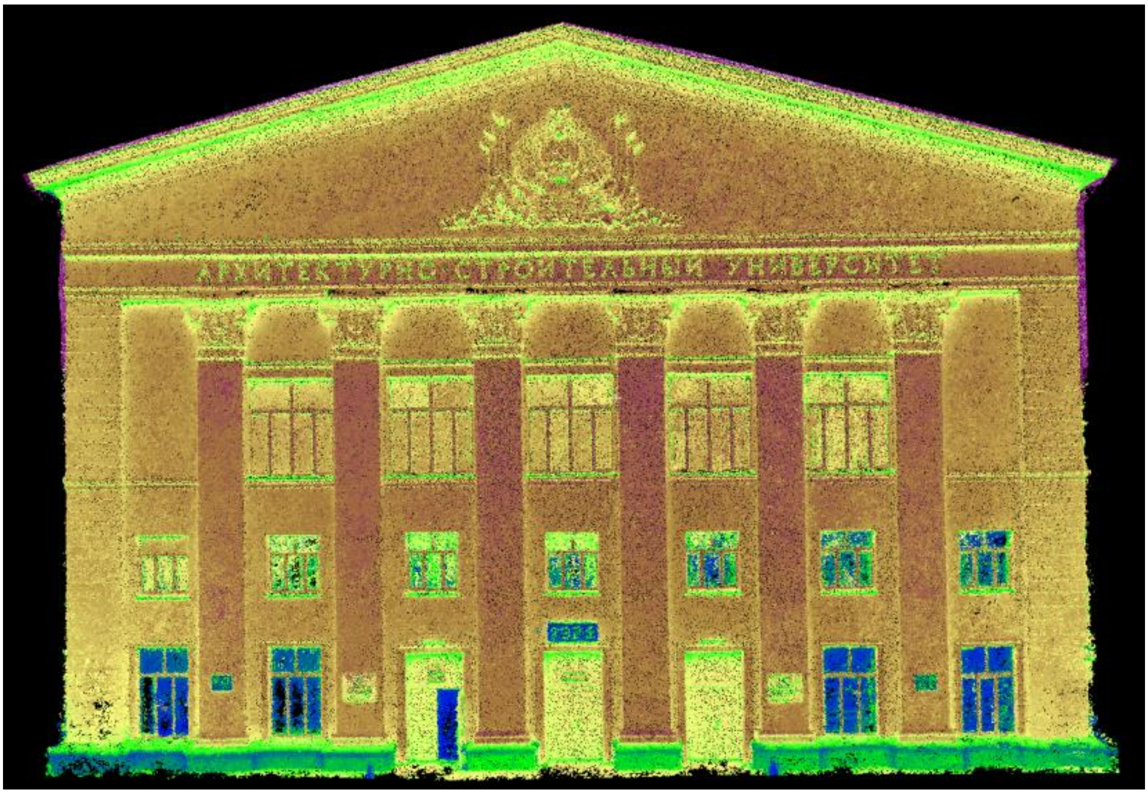

Fig. 2. The three-dimensional façade model from point clouds

Fig. 3. The three-dimensional façade model from images

As can be seen from Fig. 3, while creating a vector model from a point cloud, its edges and oblique angles are smoothed out (blurred), for example, the corners of window embrasures and the edges of columns.

The vector model was also created using TLS data (Fig. 4) and Leica Cyclone software (Fig. 5).

Fig. 4. The three-dimensional façade model from TLS point clouds

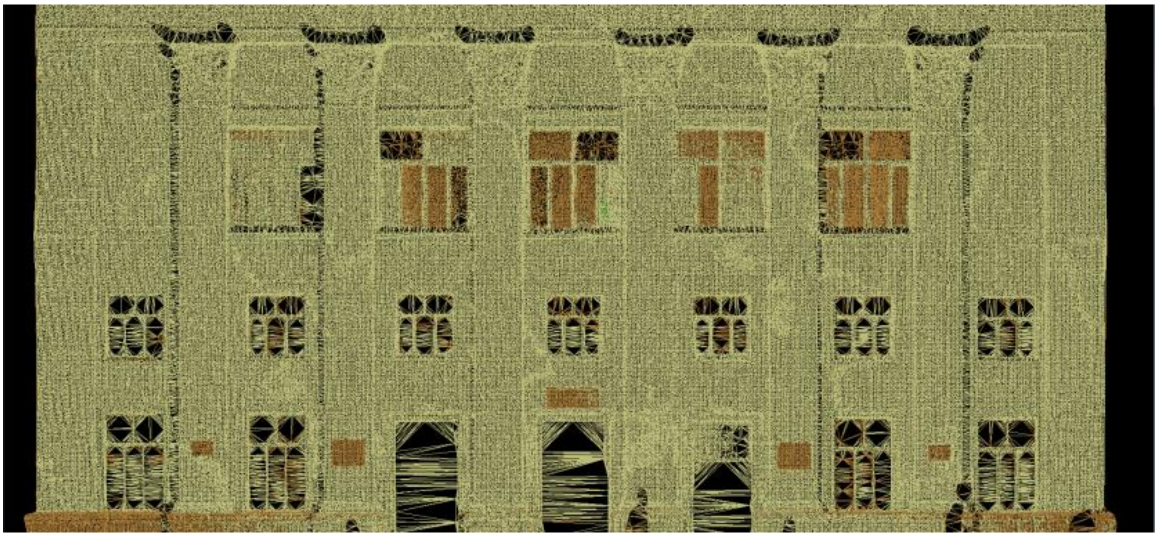

Fig. 5. The three-dimensional façade model from images

Three-dimensional façade models from TLS point clouds shown in Fig. 2 and 4 are represented in accordance with the intensity of reflected signal.

At the next stage of data processing, the vector model from images was projected onto the TIN model created by a point cloud of laser reflections (scans) (Fig. 6), after which analytical comparison of data obtained was carried out.

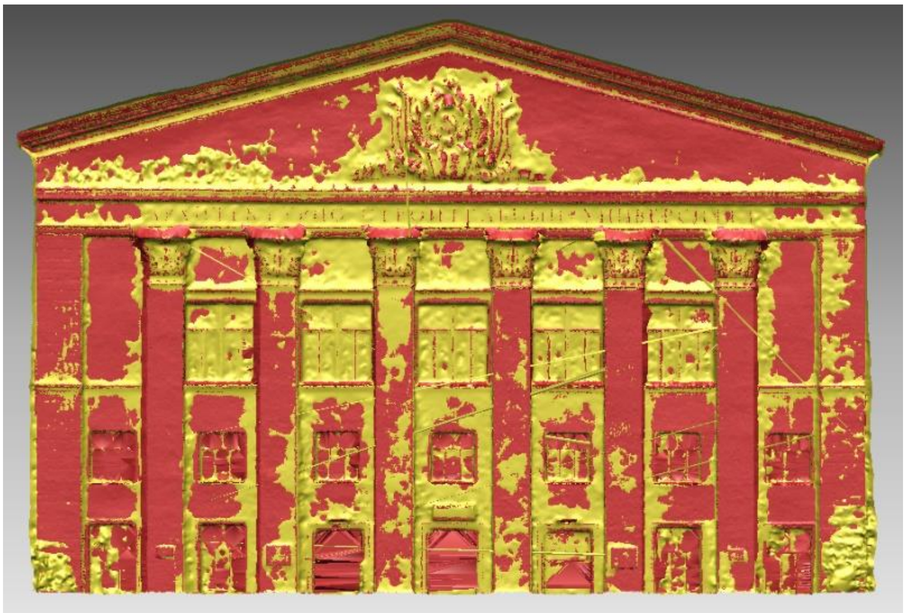

Fig. 6. Fusing three-dimensional vector façade models

The three-dimensional vector model created by TLS data is shown in Fig. 6 by red colour, whereas that of created from images taken using a non-metric digital camera by yellow.

It can be seen from Fig. 6 that the greatest discrepancies between the two surfaces are in the lower model corners This could be happened due to a lack of forward overlap between images on the object edges (in this case it was 58%), and because of a sharp turn of the wall (building edge). Significant discrepancies are also located near capitals and other relief faces, as well as in places of bending between columns, window embrasures and walls. In the upper part of the façade, deviations were appeared because of the large angle of surface inclination relative to the objective.

Comparative analysis of the two models was performed manually and automatically.

The manual method consisted in uniform distribution of 101 control points across the entire building façade surface, the coordinates of which were specified theoretically (Fig. 7).

Fig. 7. Point distribution across the façade

The Z-coordinates for all the control points on each model were determined, and the discrepancies between them were recorded. The data obtained are presented in Tab. 3.

Table 3

Discrepancies of digital models

Smooth surface								**Relief surface**							
№	**A, (m)**	**B, (m)**	x_i**, (m)**	**№**	**A, (m)**	**B, (m)**	x_i**, (m)**	**№**	**A,(m)**	**B, (m)**	x_i**, (m)**	**№**	**A, (m)**	**B, (m)**	x_i**, (m)**
1	0.448	0.440	-0.008	30	0.187	0.187	0.000	1	0.476	0.476	0.000	23	0.426	0.425	-0.001
2	0.442	0.440	-0.002	31	0.150	0.151	0.001	2	0.465	0.446	-0.019	24	0.223	0.217	-0.006
3	0.433	0.429	-0.004	32	0.204	0.204	0.000	3	0.537	0.536	-0.001	25	0.172	0.162	-0.010
4	0.363	0.359	-0.004	33	0.356	0.365	0.009	4	0.217	0.215	-0.002	26	0.243	0.240	-0.003
5	0.167	0.156	-0.011	34	0.481	0.481	0.000	5	0.466	0.459	-0.007	27	0.205	0.183	-0.022
6	0.176	0.164	-0.012	35	0.478	0.477	-0.001	6	0.778	0.773	-0.005	28	0.229	0.230	0.001
7	0.173	0.162	-0.011	36	0.461	0.456	-0.005	7	0.547	0.543	-0.004	29	0.521	0.521	0.000
8	0.540	0.541	0.001	37	0.456	0.454	-0.002	8	0.226	0.226	0.000	30	0.473	0.462	-0.011
9	0.573	0.572	-0.001	38	0.480	0.473	-0.007	9	0.501	0.478	-0.023	31	0.345	0.344	-0.001
10	0.476	0.455	-0.021	39	0.452	0.452	0.000	10	0.843	0.810	-0.033	32	0.434	0.410	-0.024
11	0.465	0.465	0.000	40	0.453	0.453	0.000	11	0.554	0.554	0.000	33	0.573	0.572	-0.001
12	0.448	0.440	-0.008	41	0.003	-0.002	-0.005	12	0.245	0.242	-0.003	34	0.437	0.405	-0.032
13	0.436	0.433	-0.003	42	0.232	0.225	-0.007	13	0.579	0.578	-0.001	35	0.251	0.250	-0.001
14	0.363	0.361	-0.002	43	0.521	0.521	0.000	14	0.420	0.420	0.000	36	0.172	0.163	-0.009
15	0.563	0.562	-0.001	44	0.463	0.463	0.000	15	0.601	0.592	-0.009	37	-0.005	-0.016	-0.011
16	0.201	0.202	0.001	45	0.452	0.448	-0.004	16	0.544	0.526	-0.018	38	0.222	0.199	-0.023

Table 3

17	0.549	0.552	0.003	46	0.172	0.163	-0.009	17	0.405	0.405	0.000	39	0.273	0.272	-0.001
18	0.495	0.499	0.004	47	0.208	0.208	0.000	18	0.234	0.234	0.000	40	0.441	0.419	-0.022
19	0.474	0.481	0.007	48	0.224	0.224	0.000	19	0.211	0.211	0.000	41	0.214	0.178	-0.036
20	0.462	0.454	-0.008	49	0.206	0.204	-0.002	20	0.190	0.198	0.008	42	0.216	0.206	-0.010
21	0.447	0.441	-0.006	50	0.204	0.204	0.000	21	0.803	0.802	-0.001	43	0.426	0.420	-0.006
22	0.408	0.411	0.003	51	0.509	0.510	0.001	22	0.558	0.558	0.000	44	0.584	0.569	-0.015
23	0.184	0.183	-0.001	52	0.473	0.464	-0.009								
24	0.009	0.009	0.000	53	0.446	0.430	-0.016								
25	0.195	0.191	-0.004	54	0.447	0.447	0.000								
26	0.206	0.206	0.000	55	0.167	0.158	-0.009								
27	0.472	0.472	0.000	56	0.228	0.221	-0.007								
28	0.447	0.447	0.000	57	0.208	0.200	-0.008								
29	0.416	0.423	0.007												

A – the value at a control point on the three-dimensional façade model created from TLS point clouds accepted as a true value;
B – the value at a control point on the three-dimensional façade vector model created from images;
x_i – the difference between the true value and the measured value

It can be seen from Tab. 3 that out of 101 measured discrepancies, only three exceed 3 cm. The all three points are located on the relief areas of façade surface, painted with white. The maximum discrepancy between two vector models was 3.6 cm.

Standard formulas used for mathematical processing of geodetic measurements [7] were applied to determine the accuracy of three-dimensional model creation from images taken by a non-metric digital camera.

The average value is calculated by the following formula:

$$\overline{X} = \frac{\sum_{i=1}^{n} x_i}{\text{n}}, \tag{1}$$

where $\overline{X}$ is the average value; x_i is the difference between the true value and the measured value; n is the number of measurements.

The mean absolute deviation is calculated by the formula:

$$MAD = \frac{\sum_{i=1}^{n} \left| x_i - \overline{X} \right|}{\text{n}}, \tag{2}$$

where MAD is the mean absolute deviation;

The standard error is calculated by the Gauss formula:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} x_i^2}{n}}, \tag{3}$$

where σ is the standard error (RMS error).

The results of mathematical calculations are presented in Tab. 4.

Table 4

Accuracy estimation

Type of surface	Average value (m)	Mean absolute deviation (m)	Standard error (m)
Smooth	-0.003	0.004	0.006
Relief	-0.008	0.009	0.013

Based on the calculations performed, it can be concluded that the measurements include a systematic error, since the modulus of the average value is close to the mean absolute deviation. That is why we have carried out an automated analysis.

Automated model analysis was performed by Rapidform software. For this purpose, maps of the mean square deviations as well as absolute ones (Fig. 8-9) between the models distributed across the entire façade surface were drawn.

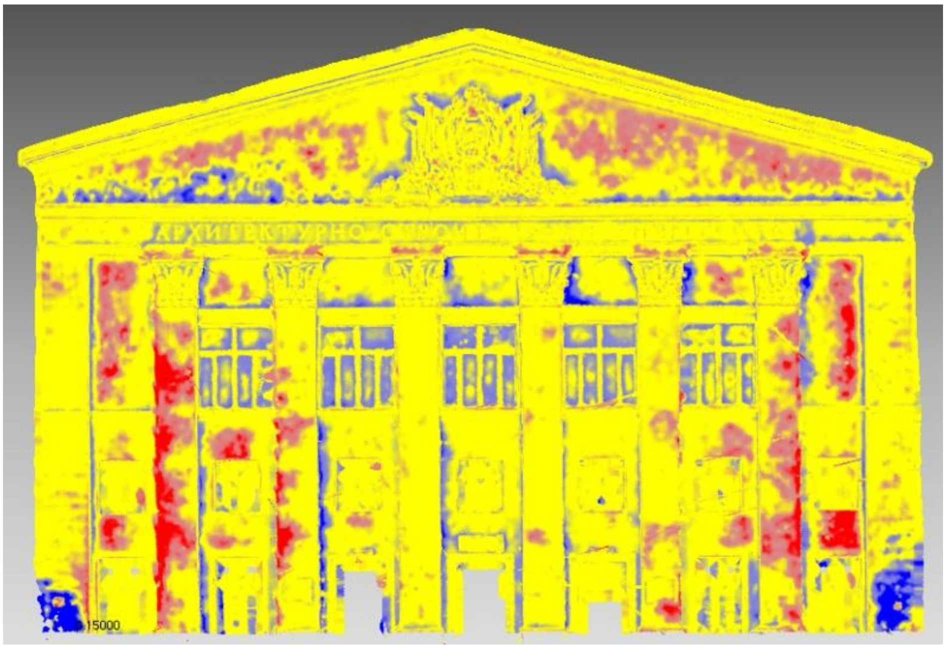

Fig. 8. Map of the mean square deviations between three-dimensional vector models

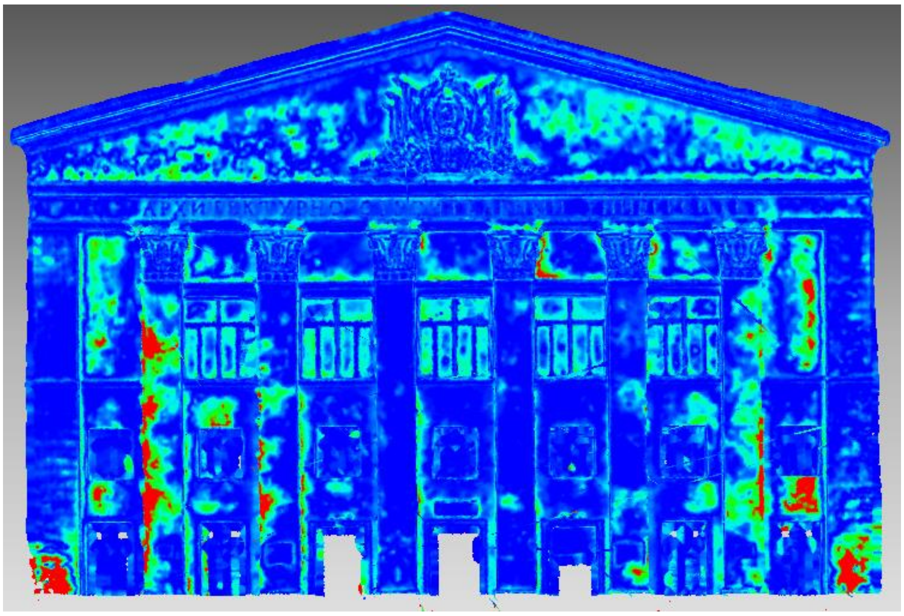

Fig. 9. Map of the absolute deviations between three-dimensional vector models

The diagram of the Gauss-Laplace distribution is shown in Fig. 10 and the map color graduation of absolute deviations between three-dimensional vector models is shown in Fig. 8.

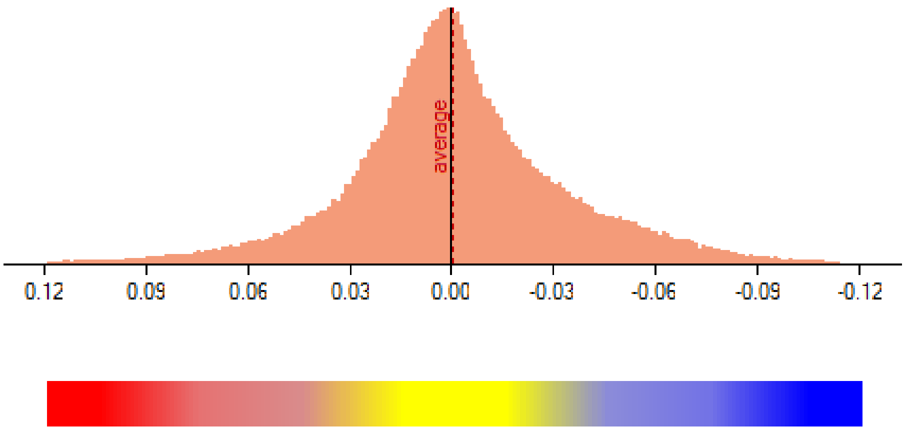

Fig. 10. A diagram of the Gauss-Laplace distribution

Fig. 11 shows the diagram of absolute deviations between vector models and the map color graduation of absolute deviations displayed in Fig. 9.

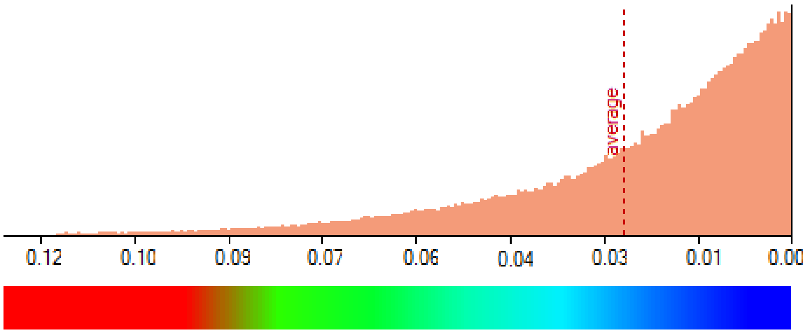

Fig. 11. A diagram of the absolute deviations

The values on both diagrams are in meter.

It is evident from Fig. 9 that the deviations between vector models created have a maximum at places of surface bends because of corner smoothing.

The following data obtained from the automated analysis are presented in Tab. 5.

Table 5

Accuracy estimation

Average value (m)	Mean absolute deviation (m)	Standard error (m)
-0.0002	0.027	0.040

It is necessary to take into account the fact that the accuracy of three-dimensional vector model creation from images taken by a non-metric camera was calculated regarding to its comparison with that of from TLS data. In this case, the actual accuracy of photogrammetric data according to our expert analysis is as high as 10 - 15% because the scanning error is not equal to 0.

Conclusions. The results of analysis allows for the following conclusions.

The accuracy of the three-dimensional façade model from images taken by a non-metric camera as a whole is comparable with respect to that of the model created from TLS data. However, there are discrepancies caused by smoothing and "blurring" the object edges and sharp corners. The discrepancies also appear in case of ground-based oblique photography of objects. To eliminate these discrepancies, it is preferable to use an unmanned aerial vehicle (UAV) with a fixed camera for right angle photography. It should be mentioned that the use of non-metric digital cameras are preferable for surveying/photography of building façades which have not complex decorative elements.

The following recommendations were developed for surveying/photography of building façades and post-processing of images:

– Photography should be carried out with a minimum angle (forward-backward);
– The frame should be with the minimum turn;
– Forward and lateral overlap should be provided according to the requirements stated in the technological documentation of Agisoft PhotoScan software;
– Photography is preferable in cloudy weather;
– It is recommended to use a tripod providing stability for the camera.

The advantages of using non-metric digital cameras in comparison with TLS are as follows:

– Low-cost equipment;
– Light-weight camera for photography without a tripod.

The disadvantages of photography using a digital camera are:

– Longer processing time;
– The lower precision of three-dimensional models.

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В. Середович, И. Камнев

АНАЛИЗ ТРЕХМЕРНОЙ ВЕКТОРНОЙ МОДЕЛИ ФАСАДА, СОЗДАННОЙ ПО ФОТОГРАММЕТРИЧЕСКИМ ДАННЫМ

В представленной работе приведены результаты анализа точности трехмерной векторной модели фасада здания, полученной по материалам фотограмметрической съёмки. Проведенный анализ базировался на аналитическом сравнении трехмерных векторных моделей фасада здания, созданных по материалам фотограмметрической съёмки цифровой неметрической камерой и наземного лазерного сканирования. Фотограмметрическая модель фасада была создана в автоматическом режиме. Для выполнения анализа трехмерная модель, которая была создана по данным наземного лазерного сканирования, была принята за исходную, то есть такую, для которой погрешностями координат точек можно пренебречь. Во время исследования фотограмметрическая модель была наложена на исходную модель, после чего были измерены отклонения между характерными точками на фасаде здания. Были выполнены оценки точности фотограмметрической модели, созданной цифровой неметрической камерой. Проведенный анализ позволил также установить места и характерные участки фасада, которые моделируются хуже на фотограмметрической модели при использовании автоматического метода создания трехмерной модели. Выявленные недостатки фотограмметрической модели вызваны преимущественно значительными углами наклона фотоснимков и возникновением вследствие этого «мертвых зон». Для преодоления этой проблемы рекомендуется дополнять материалы наземной фотограмметрической съёмки материалами фотосъемки с беспилотных летательных аппаратов.

Ключевые слова: *наземное лазерное сканирование, наземная фотограмметрия, оценка точности, неметрические цифровые камеры, трехмерная модель.*

В. Середович, І. Камнев

АНАЛІЗ ТРИВИМІРНОЇ ВЕКТОРНОЇ МОДЕЛІ ФАСАДУ, СТВОРЕНОЇ ЗА ФОТОГРАММЕТРИЧНИМИ ДАННИМИ

У представленій роботі наведено результати аналізу точності тривимірної векторної моделі фасаду будівлі, отриманої за матеріалами фотограмметричного знімання. Проведений аналіз базувався на аналітичному порівнянні тривимірних векторних моделей фасаду будівлі, створених за матеріалами фотограмметричного знімання цифровою неметричною камерою та наземного лазерного сканування. Фотограмметричну модель фасаду створено в автоматичному режимі. Для виконання аналізу тривимірна модель, створена за даними наземного лазерного сканування, була прийнята за вихідну, тобто таку, для якої похибками координат точок можна знехтувати. Під час дослідження фотограмметричну модель накладено на вихідну модель, після чого було виміряне відхилення між характерними точками на фасаді будівлі. Виконано оцінювання точності фотограмметричної моделі, створеної цифровою неметричною камерою. Проведений аналіз дав змогу встановити також місця і характерні ділянки фасаду, які моделюються найгірше на фотограмметричній моделі під час використання автоматичного методу створення тривимірної моделі. Виявлені недоліки фотограмметричної моделі викликані переважно значними кутами нахилу фотознімків і виникненням внаслідок цього «мертвих зон». Для подолання цієї проблеми рекомендується доповнювати матеріали наземного фотограмметричного знімання матеріалами фотознімання з безпілотних літальних апаратів.

Ключові слова: *наземне лазерне сканування, наземна фотограмметрія, оцінка точності, неметричні цифрові камери, тривимірна модель.*

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K. Vach, *PhD,*
EuroGV s.r.o. – geodetic and photogrammetric surveys

APPLICATION OF 3D TECHNOLOGY FOR MODELLING OF ARCHITECTURAL MONUMENTS IN THE CZECH REPUBLIC

The paper is devoted to consideration the questions of 3D technology application for modelling of architectural monuments in the Czech Republic. 3D in case of conservation of historical and cultural monuments means the processing of measured data with the required contents in the local system of coordinates and in a chosen scale. According the results obtained it is necessary to determine the requirements for measuring accuracy. The main goal of our research is early detection of errors in 3D images of actual building behavior and their exception, as well as introduction of new