



UAV PHOTOGRAMMETRY FOR ROAD SURFACE MODELLING

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Abstract. Recently, the interest of Unmanned Aerial Vehicle application in photogrammetric environment for roads observation and monitoring has increased in many countries, in Lithuania as well. The experimental object for demonstration of capability and efficiency of aerial vehicle-based remote sensing technology for road data collection was a western bypass of Vilnius. The platform of the model *UX5 Trimble* with mounted camera *Sony NEX-5R* was applied for gaining images. The implemented means are mobile and not expensive. Photogrammetric technique with software package *Business Center Photogrammetry Module* was applied for the modelling of images. The correctness of digital surface model generally depends on camera resolution, flight height and accuracy of ground control points. The coordinates of control points were determined using Global Positioning System *Trimble R4*. Paper demonstrates results of a new technology application possibilities for linear object (road) mapping and accuracy evaluation of spatial models. The road points positioning accuracy investigation was carried out in consideration with geodetic control measurements. The average root mean square error for the points coordinates is 2.94 cm, and standard deviations – 2.78 cm. Analyzing coincidence or mismatches of Vilnius western bypass project data with photogrammetric product, not significant discrepancies of road section features were determined. The cost consideration of Unmanned Aerial Vehicle in conjunction with photogrammetry employment at experimental object is presented.

Keywords: Unmanned Aerial Vehicle, photogrammetry, image processing, orthophoto, accuracy, road observation.

1. Introduction

From about 2007 and up to now, the collection of cartographic data from images taken by sensor (digital camera) integrated in a platform named Unmanned Aerial Vehicle/System (UAV/UAS) has increased significantly. The interest of UAV great potential for various applications as well as for road conditions and parameters determination is increasing in many countries, in Lithuania also.

UAS aerial imaging solutions are being used to perform boundary and topographic surveys, site and route planning, progress monitoring, and build process inspection, volume determination, vegetation health and disaster analysis, with employed new technologies as laser scanning (Mill *et al.* 2011, 2014).

The UAV describes a platform, which operates remotely controlled, semiautonomous or full autonomously without a pilot sitting in the vehicle. It is a modern and

low-cost application compared to the piloted aerial photogrammetry. Various types, classes and categories of UAVs are used for cartographic data collection. With the UAV, due to its small size, can be taken photography very close to an object of very small space; territories that are shielded by trees or water bodies, narrow city streets, road network, etc. (Eisenbeiss 2009; Neitzel, Klonowski 2011; Verhoeven 2009).

The use of professional digital photogrammetric cameras demonstrates the benefits of digital image recording for terrain data generation. Digital photogrammetry methods are applied for processing images. Software packages used in Digital Photogrammetry can process the UAV images. The data gained from UAS are characterized by narrow frame, large distortions, irregular array and broad rotating angle. Because of such features the software for UAV image processing adopts advanced image matching

techniques for automatic aerial triangulation. By applying advances matching and filtering technique, Digital Surface Model (DSM) and Digital Elevation Model (DEM) can be produced rapidly. Elevation data are important for generating and updating terrain models (Haala *et al.* 2010; Kraus 2007). It is extremely important that the digital terrain model of the surface is created in required quality (Harvin, Lucieer 2012; Nurminen *et al.* 2013; Ruzgienė 2010).

The application of UAV when processing images by Photogrammetry techniques is up-to-date technology and can be applicable for road investigation. Road network is the lifeline of human activities, therefore, road data is very important in transportation management and leads to traffic safety as well. At present, information about the existence, locations, dimensions and condition of roads is usually collected in not fast, may be dangerous, and more expensive processes. As well, the importance of timely identification of road deformation cannot be neglected.

Image processing algorithms analyze the acquired images, perform image orientation, and generate 3D models and orthophoto of appropriate surface images. Such products allow to measure the road surface distresses (potholes, ruts, etc.) in more detail. The generated 3D road images permit better visualization and inspection of road features. The data can be easily integrated as video products for road virtual representation (Zhang 2010).

The goal of this research is to demonstrate the capability and efficiency of UAV-based remote sensing technology for road data collection, to evaluate the quality of generated products, to estimate the labour costs.

2. Technological features

The use of UAV system for mapping of linear objects such as roads leads to a new level of surveying technology. The technical means of UAS *Trimble UX5* turns to a new standard in mapping combining a robust and highly user-friendly system with a custom-designed camera. The *Trimble UX5* operates productively all day long and helps for all who require the highest accuracy and more efficiently work. Trimble UAS Aerial Imaging solution is designed for the reduction of time and cost collecting the aerial data as well guarantees the reliability of mapping product (Trimble 2014).

Through one UAV flight, the digital camera can gather a large number (hundreds) of images. The camera mounted at *UX5* has the imaging sensor that captures very sharp, color-rich images. The Trimble Access Aerial Imaging application operates the *Trimble UX5* and is the software for planning aerial flight missions, performing pre-flight checks. Many of the *Trimble UX5* checks are automatically verified by the software. The *Trimble UX5* can be ready to fly in approx 5 min.

During UAV take-offs, the risk elements should be clarified: obstacles, wind speed (maximum 65 km/h), etc.

The *UX5* climbs in a straight line until the appointed flight height is reached, navigation will start towards the flight area waypoints. Maximal roll angle is 40°.

When the flight is finished *UX5* will automatically start the landing sequences. When UAV flight mission is finished, the collected photos are verified by loading images from camera's card into computer. These actions are proceeded on the field in real time. For image data acquisition the following general workflow is applied: definition of the project, flight planning, independent photogrammetric flight mission and checking of the image data quality (Haala *et al.* 2011; Rudinskas 2011).

After capturing the images, using different platforms and sensors, the main photogrammetric procedures are as follows: aerial triangulation, images orientation, creation of surface models, orthophoto generation and vector data collection for GIS or cartographic needs. The coordinates of ground control point are usually measured using Global Positioning System (GPS) when it is needed to establish the relation between images and object coordinates (McGlone 2004; Rock *et al.* 2011).

Trimble offers UAS image data processing software with modern computer-vision algorithms combined with proven state-of-the-art photogrammetric techniques to produce deliverables with the highest accuracy, with minimal manual interaction. The *Trimble Business Center (TBC) Aerial Photogrammetry Module* was developed for professional land surveyors working with small UAS from Trimble.

Aerial images are imported to *TBC Photogrammetry Module* in consideration with their locations, orientations, and camera calibrations parameters. The use of photogrammetric methods allows correction of the image orientations. The *TBC Photogrammetry Module* at first performs the adjustment with photo tie points – the software automatically finds tie points in all images. Matched photo tie points are usually distributed densely, even in challenging low of terrain texture.

The aerial triangulation technique is applied for adjustment of the aerial photo stations. At first, traditional aerial triangulation algorithms based on bundle block adjustment is used. The collinearity equations are used in constructing the observation equations. The observation equations with the stochastic constraints are expressed as (Choi, Lee 2013):

$$\begin{bmatrix} y_{11} \\ z_1 \end{bmatrix} = \begin{bmatrix} A_{e11} & A_{p11} \\ K_1 & 0 \end{bmatrix} \begin{bmatrix} \xi_{e1} \\ \xi_{p1} \end{bmatrix} + \begin{bmatrix} e_{y11} \\ e_{z1} \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} e_{y11} \\ e_{z1} \end{bmatrix} \sim \left(0, \sigma_0^2 \begin{bmatrix} P_{y11}^{-1} & 0 \\ 0 & P_{z1}^{-1} \end{bmatrix} \right)$$

where e_1 , p_1 – parameter vectors (for exterior orientation and ground points); y_{11} – observation vector (for tie points); A_{e11} , A_{p11} – matrices derived from differentiation of the collinearity equations (corresponding to the tie points); z_1 – observation vector of the exterior orientation parameters; K_1 – matrix associated constraints; e_{y11} , e_{z1} – error vectors; σ_0^2 – unknown variance component; P_{y11}^{-1} – cofactor matrix of e_{y11} ; P_{z1}^{-1} – cofactor matrix of e_{z1} , reflecting precision of the GPS.

The observation equations are:

$$y_1 = A_{11}\xi_1 + e_1, e_1 \sim (0, \sigma_0^2 P_1^{-1}), \quad (2)$$

where $A_{11} = \begin{bmatrix} A_{e11} & A_{p11} \\ K_1 & 0 \end{bmatrix}$, $\xi_1 = \begin{bmatrix} \xi_{e1} \\ \xi_{p1} \end{bmatrix}$,

$$e_1 = \begin{bmatrix} e_{y11} \\ e_{z1} \end{bmatrix}, P_1 = \begin{bmatrix} P_{y11} & 0 \\ 0 & P_{z11} \end{bmatrix}.$$

Applying the least squares adjustment method, the normal equation is derived:

$$N_{11}\xi_1 = c_1, \quad (3)$$

where $N_{11} \equiv A_{11}^T P_1 A_{11}$, $c_1 \equiv A_{11}^T P_1 y_1$, $\xi_1 = \begin{bmatrix} \xi_{e1} \\ \xi_{p1} \end{bmatrix}$.

Representing the sub-block of the normal matrix, the normal equation are rewritten:

$$\begin{bmatrix} N_{e11} + N_{z1} & N_{ep11} \\ N_{ep11}^T & N_{p11} \end{bmatrix} \begin{bmatrix} \xi_{e1} \\ \xi_{p1} \end{bmatrix} = \begin{bmatrix} C_{e11} + C_{z1} \\ C_{p11} \end{bmatrix}, \quad (4)$$

where $N_{11} \equiv \begin{bmatrix} A_{e11}^T P_{y11} A_{e11} + K_1^T P_{z1} K_1 & A_{e11}^T P_{y11} A_{p11} \\ A_{p11}^T P_{y11} A_{e11} & A_{p11}^T P_{y11} A_{p11} \end{bmatrix}$,

$$c_1 \equiv \begin{bmatrix} C_{e11} + C_{z1} \\ C_{p11} \end{bmatrix} = \begin{bmatrix} A_{e11}^T P_{y11} y_{11} A_{p11} + K_1^T P_{z1} z_1 \\ A_{p11}^T P_{y11} y_{11} \end{bmatrix}$$

The inverse of the normal matrix is represented:

$$N_{11}^{-1} = \begin{bmatrix} N_{e11} + N_{z1} & N_{ep11} \\ N_{ep11}^T & N_{p11} \end{bmatrix}^{-1} = \begin{bmatrix} N_{r1}^{-1} & U_1 \\ U_2^T & U_3 \end{bmatrix}, \quad (5)$$

where $N_{r1}^{-1} = (N_{e11} + N_{z1} - U_1 N_{ep11}^T)^{-1}$, $U_1 = N_{ep11} N_{p11}^{-1}$,
 $U_2 = -N_{r1}^{-1} U_1$, $U_3 = N_{p11}^{-1} + U_1^T N_{r1}^{-1} U_1$.

For this computation it is necessary to calculate the inverses of the matrices N_{p11} and N_{r1} .

The estimation parameters are computed as:

$$\begin{aligned} \hat{\xi}_{e1} &= N_{r1}^{-1} (c_{e11} + c_{z1}) - N_{r1}^{-1} N_{ep11} N_{p11}^{-1} c_{p11}, \\ \hat{\xi}_{p1} &= N_{p11}^{-1} (c_{p11} - N_{ep11}^T \hat{\xi}_{e1}). \end{aligned} \quad (6)$$

Aerial images are used for creation digital surface models, for orthophotography and 3D point clouds. *TBC Photogrammetry Modules'* point cloud generation algorithms are based on more than 30 years technology evolution using matching and DTM generation algorithms. The fully automatic process guarantees precision, providing accurate results at a speed of about 3 s per image. This software package is designed for surveyors employing *Trimble UAS*

and delivers such products: high resolution orthomosaic, point cloud, results of volume calculations, etc.

3. Experimental procedures

The fly of UAV with mounted digital camera was performed by the Joint-Stock Company (UAB) InfoEra – the leader of engineering IT solutions in Lithuania. The standard requirements for flight planning and realization were used. The aim was to perform short flights and acquire image data of linear object – bypass. The dependence on good meteorological conditions and appropriate flying height are very important when executing the flight.

The flight was executed over the Lazdynai area, a region of Vilnius. The experimental object – 3 km road section (about 60 ha) of the western bypass was chosen advisably (Fig. 1). The site for experimental flight was of equal geomorphologic landforms, the main focus was on capturing image data suitable for photogrammetric processing. The site was the newly built road section – the human-created object and surroundings. The mean altitude (elevation) of area is about 145 m, maximal height difference – approx 30 m. The flight mission was executed at the end of September 2014, on good meteorology.

3.1. Image data acquisition

The fixed-wing UAV, model *UX5 Trimble* (Fig. 2) with mounted professional camera *Sony NEX-5R* was applied for the image acquisition.

The fixed-wing *UX5* is low cost and weight UAV platform with foam construction. A wingspan is of 1.0 m and the weight is 2.5 kg. Dimensions of UAV are

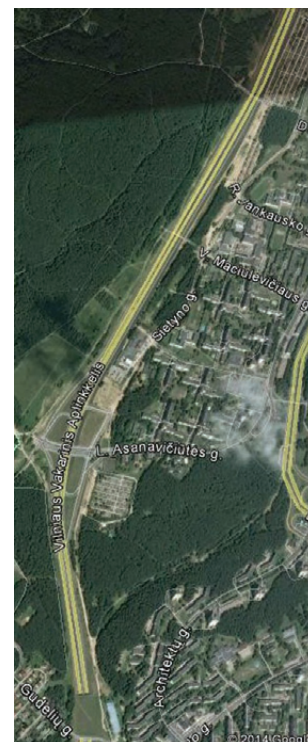


Fig. 1. Experimental area in Google Earth application – the section of Vilnius western bypass (Source: <https://earth.google.com/>)

100×65×10 cm. The UAV cruise speed is 80 km/h (about 22 m/s) and endurance to fly up to 50 min on low wind and light rain. A flight range is approx 60 km, adding some for launch and landing. The maximal communication and control range is up to 5 km.

The Aerial Ground Level (AGL) – the possible flight height during images acquisition ranges from 75 m to 750 m, depending on the required images resolution. The Ground Sample Distance (GSD) – resolution is 2.4 cm to 24 cm.

The guidance of UAV platform can be full automatic, semi-manual or manual. The take-off of platform, flight and landing on the surface can be executed in an automatic or manual mode. The flight planning programme *Trimble Aerial Imaging* allows optimal guidance of the flight.

The images over the area were taken using a high-resolution professional camera *Sony NEX-5R* with fixed-optics *Voigtlander* lens.

Main camera's features are: a focal length is of 15 mm; APS-C sensor, incorporated with 16.1 Mega pixels (full



Fig. 2. UAV used as platform for taking images over area



Fig. 3. Aerial imaging of bypass: flight strips numbered from 1 to 7



Fig. 4. High resolution image over model area

frame size of image is 4912×3264 pixels); sensor's area 365.04 mm² (23.40×15.60 mm); pixel size 4.8×4.8 μm. Fixed-optics *Voigtlander* lens increase the stability of the camera's internal geometry.

Such small pixel size determines the light sensitivity – sharp images can be acquired in all weather conditions between sunrise and sunset, and a higher shutter speed is used to eliminate motion blur. Even at slower flying speeds, a wind gust resulting in roll or a small change in pitch, longer exposure times can lead to motion blur. Image blur causes the radius of uncertainty in tie point matching to increase by a factor of 4, which has a direct effect on the resulting vertical accuracy in the point cloud and DSM.

Integrated GPS module allows to determine geodetic coordinates of each image projection center during the flight.

Prior to a flight camera is turned on, ISO is determined to auto mode, F-value 4.5, the camera's focus is fixed and shutter speed is regulated depending on weather conditions and terrain features. The *Trimble Aerial Imaging* operates not only UAV, but also manages camera exposition. Therefore, the image collection becomes fully automatically.

After the check of the fixed-wing UAV parameters, the flight mode was shifted to the automated flying. When UAV achieves the appointed high, the process of taking pictures starts.

The flight's height was approx 75 m above the ground, because there was a requirement to collect images at a GSD of up to 3 cm. GSD is determined using the following formula:

$$GSD = p \left(\frac{AGL}{c} \right), \quad (7)$$

where p – CCD pixel size, μm; AGL – aerial ground level, m; c – camera focal length, mm.

The two flights were generated – two paths involve 7 strips (Fig. 3). One path (road section) with 596 images, one photogrammetric block covers 291 722.5 m² and other (in succession) – 594 images covers 290 876.5 m². One image model covers the area of 4845 m² on the ground.

The overlap of images is important for getting a high-quality mapping product. When the number of overlapped images is only two or three it can lead to poor quality of generated product. Best results can be obtained when over 5 images are overlapped. It is recommended 70% or 80% overlaps of images because of UAVs instability and dependency on wind speed (Luhmann et al. 2006).

Approx 90% of the test area images are overlapped of 3–4 images and that is acceptable. The side overlaps of images are about 80%.

3.2. Images processing and analysis of results

The high-resolution images obtained from UAV system were used for processing in a photogrammetry application (Fig. 4). Concerning the effectiveness of image processing, cartographic data collection and experimental investigations, all images (in total 1190) have been applied for photogrammetric mapping.

The main characteristics of images are as follows: original (current size) – 4912×3264 pixels; resolution – 350×350 dpi; image pixel size (from dpi) – 72.57 μm ; image print size (frame) – 35.6×23.7 cm; image size on the ground 106.8×71.1 m; original (current) color – 24 bits, memory size 5–7 Mb. The scale of images is 1:300–400 determined from relation of GSD and image pixel size.

Geodetic control network used for exterior images orientation was created by two ways: arranging signalized points (targets) and selecting natural ground points (e.g. pavement's slabs corners, centers of well covers, poles, etc.) clearly identified in the images.

The targets were arranged by the sheets of size 40×40 cm made from corrugated plastic. The signals were set up in such a way: having selected some places on the road's hard cover, the chess pattern of size 20×20 cm was painted using purple *Soppec Fluo TP* paintings; screwing of plastic nails with the hole in the middle for pole centering over the target.

Ground control points (GCP) (in total 42 including 9 signalized) were distributed in various heights and parts of the experimental model/ territory. Such amount of GCP's was applied in order to produce the road's mapping product of the highest quality; traditionally the minimum number of GCPs is 5, spread at corners and in the middle (one point) of test area. The distribution of GCPs is presented in Fig. 5.

Ground control points were coordinated using GPS *Trimble R4* model 3 (GLONASS enabled) with *Trimble Slate controller* and *Trimble Access* software. The ellipsoidal height of GPS points is determined with the accuracy up to ± 30 mm. The average accuracy of ground control point positioning by the GPS (determining of planimetric coordinates) is about 15 mm. Images from UAV are significantly under tilt. Therefore, seeking to increase the accuracy of images transformation, recommendation is to apply appropriate number of ground control points, i.e., to use more points than traditionally is required.

Photogrammetric image processing. The photogrammetric software package *TBC Photogrammetry Module* was used for experimental images processing. This package is a professional processing software, developed at *TRIMBLE* Geospatial Division, Westminster, Colorado, USA and can be applied for converting thousands of aerial images, taken by lightweight unmanned aerial vehicle into geo-referenced surface models. The newly released *TBC Photogrammetry Module* is compatible with the modern *Trimble UX5* Aerial Imaging Solution. Such means allows to process aerial images accurately using collected ground survey data in an integrated workflow. The deliverables include: dense point cloud, digital surface model, orthophoto generation and an orthomosaic. This module is successfully applied for surface analyses: for contour generation, profiling, volume calculation, etc.

Using the package *TBC Photogrammetry Module* all images from UAV were processed. DSM from point cloud and orthophoto map were generated.

Compiling orthophoto map for the section of bypass at experimental area, not all determined control points were

involved in the process of UAV images transformation in order to investigate the quality of the mapping results. The demand of such investigations arises because the UAV flight has significant dependence on weather conditions and UAV is under the considerable tilt because of its light weight.

Images rectification for orthophotos generation was carried out using 17 ground control points the coordinates of which were determined by GPS in the investigated road environment. Fig. 6 shows the fragment of generated orthophotos.

Evaluation of results. The research was performed in the following aspects:

- determining the accuracy of generated mapping products for road section;
- fixing coincidence or mismatches of bypass project data with generated orthophotomaps from UAV images.



Fig. 5. Distribution of GCPs (marked by white triangles – signalized points, green – check points, red – control points) on the test area



Fig. 6. The fragment of generated orthophoto at experimental area

At first, the quality (accuracy) of generated data set was investigated evaluating absolute accuracy that expresses the position error of a reference GCPs and its corresponding coordinates in the 3D model. For this task, 25 points were checked, whose coordinates are known from GPS measurements, but not involved in image transformation. The residuals in x and y at every check points as well as the resulting standard deviation do not exceed the half of image pixel size, i.e. – 0.036 mm and 13 mm on the ground. Fig. 7 visually shows such minor (negligible) check point position discrepancy.

For the next step, investigation of the terrain points, selected at generated orthophotomaps from UAV imagery, positioning accuracy in consideration with geodetic control measurements was performed – checking the exterior accuracy.

On the images of the test area 68 well-seen points has been selected and coordinates of these points were measured on the site using GPS. The coordinate differences (orthophoto – GPS) have been calculated and point's position accuracy

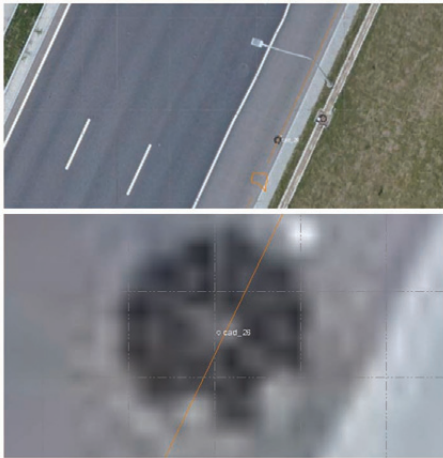


Fig. 7. Discrepancy of check point position (original and zoomed)

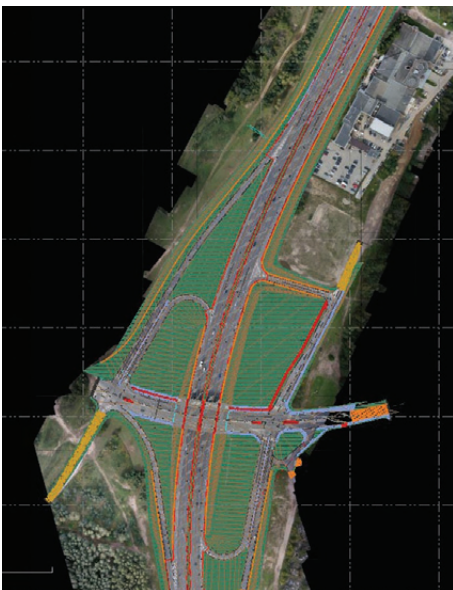


Fig. 8. Fragment of generated orthophoto with road (bypass) project data overlaid

was evaluated determining the estimators: Root Mean Square Error ($RMSE$) and Standard Deviation StD (σ).

The measurements in images was performed with the accuracy up to 0.05 mm (15 mm on the ground – test site). The determined average RMS for the point's planimetric coordinates is 2.66 cm, and StD value – 2.50 cm.

The accuracy of the point's height differences has been calculated using the following formula (8).

$$\sigma_{\Delta Z} = \sqrt{\frac{1}{n} \left(\sum_{i=1}^n (\Delta Z_i)^2 - n(\Delta \bar{Z})^2 \right)}, \quad (8)$$

where $\Delta Z = Z_{img} - Z_{geod}$ m; $\Delta \bar{Z}$ – mean of deviations; n – number of checked points.

The determined RMS for the point's heights differences is 3.23 cm, and standard deviations value – 3.06 cm.

For the evaluation of results the following rule of thumb has been appointed – accuracy is in order of twice the GSD in x and y direction and three times GSD in the altitude. Moreover, the Trimble Corporation declares such UAS data accuracy evaluation results (GSD = 2.4 cm): the average and max errors in x and y directions are – 2.4 cm and 3.8 cm (one and 1.6 times GSD) respectively; in z direction – 3.8 cm and 6.0 cm (1.6 and 2.5 times GSD).

Concerning accuracy data mentioned above and accepting as limitations, in this particular case, when UAV *Trimble UX* with mounted camera *Sony NEX-5R* flew over experimental area at a height of 75 m, the accuracy requirements would be applicable: in x and y direction – 4.0 cm and in z – 6.5 cm.

Finally, the available project data of Vilnius western bypass was compared with generated orthophoto and analyzed. Fragment of the generated orthophoto from UAV images with road (bypass) project data overlaid is presented in Fig. 8. The comparative analysis of these two products was carried out evaluating the relative accuracy. The maximal features discrepancy of project realization has been detected – it is up to 5 cm.

The quality of mapping products (orthophotomaps) derived from images mainly depends on the quality of created Digital Terrain Model (DTM). DTM, generated by image matching technique, depends on the quality of the images, image orientations, the correlation limits, interpolation parameters, terrain features, etc. and significantly influences to the objects position on the orthophotomaps. The errors distributions can be unequal in the whole areas of orthophoto. Modelling the particular structures such as roads with viaducts, bridges, etc., the correctness of DTM, as well orthophotomaps are very important. The investigation of the aspects mentioned above is an outcome of this research and should be performed in future.

Cost consideration. At the time when various technologies are available for the image acquisition, management and processing, it is important to consider cost aspects for a certain application. In general, the price of the product is composed of an actual expenses plus overheads. Overheads vary greatly with salary structure of

administrative services and the amount of taxes to be paid (Konecny 2003).

The example of cost strategy is presented, based on the executed UAV flight mission over Vilnius western bypass and construction of mapping product.

The area, covered by images in the flights, relation with height of flight is one of important factors for the UAV mission duration and project cost evaluation. Table 1 presents data of imaging area regarding the different GSD.

Before the UAV flight mission the preparation works are as follows: reconnaissance of territory, planning of GCPs, marking of GCP on the area, determination of signalized and natural (features) points coordinates using geodetic techniques. The works efficiency for the UAV flight mission is presented in Table 2.

The performance details of photogrammetric model with 596 images (one path) for aerial triangulation (AT), DEM generation, digital orthophoto modeling (DOM) are listed in Table 3.

Concerning data mentioned above, the aerial photography costs consist of a base cost for preparation works (transportation and overheads as well) plus a charge for the image area.

Table 4 shows the price-list in consideration of mapping area.

The generation of mapping production (automated processes) is based on costs per image (0.5 €) plus labour (manual) costs per hour (5 €) – total 340 € for processing of 600 images.

The average total costs for UAV (one path) executing over Vilnius western bypass and image processing is 2340 €.

The costs variation for UAV Photogrammetry (aerial mapping) application depends on product providers calculations concerning special employment as well.

4. Conclusions

1. The interest of Unmanned Aerial Vehicle's great potential for the determination of road condition and parameters is rising in many countries, also in Lithuania. Unmanned Aerial Vehicle in conjunction with photogrammetry provides low cost, small area, prompt data collection used for image processing.

2. The technical means such as the fixed-wing Unmanned Aerial Vehicle platform of model *UX5 Trimble* and camera *Sony NEX-5R* with fixed-optics lens *Voigtlander* used for executing the flight mission over western Vilnius bypass test area demonstrates modern technology employed for road and environment imaging.

3. The software *Trimble Business Center Photogrammetry Module*, used for creation of photogrammetric deliverables (point clouds, orthomosaics, and elevation models, etc.), operates two-four times faster due to the advance algorithm. The system allows quantitative measurements (collection of road condition data) from elaborated images obtained from Unmanned Aerial Vehicle, does not requiring field work. It enables more quickly, efficiently

Table 1. Imaging area regarding GSD and AGL (*UX5 Trimble*, camera with *Voigtlander* lens)

GSD, cm	AGL, m	Image size on ground, m
2.4	75.0	117.8×78.3
3.0	93.7	147.3×97.9
5.0	154.2	245.6×163.2
10.0	312.5	491.2×326.4
20.0	625.0	982.4×652.8
24.0	750.0	1178.9×783.4

Table 2. Efficiency for the UAV flight mission

Stages	Efficiency, h
Reconnaissance	1
GCP projecting*	1
Signal preparation and marking**	1.5
Coordination of GCPs*	1
UAV flight mission (one path), 2 executers	2
Total	6.5

Note: * – the number of GCP – 47; ** – signals – 9.

Table 3. Images processing details

Process	Operation	Performance duration, h	
		Auto	Manual
AT	Data preparation	–	0.5
	Tie-point matching	4	
	GCP measuring	–	1.5
	Block adjustment	1	
DEM	Matching	3	
	Filtering	0.5	
	Post-processing	0.5	
	Editing	–	2
DOM	Ortho rectification	2	
	Color adjustment	1	
	Mosaicking	3	
	Line editing	–	4
Total		15	8

Table 4. Price-list for aerial mapping

Area, ha	UAV aerial photography cost, €		
	GSD 3 cm	5 cm	10 cm
up to 2	570	340	280
2–5	740	400	280
5–10	970	450	400
10–15	1430	510	570
15–25	2000	860	680
50–100	3400	1400	800

and safely to collect data needed for road surface positioning. The road data are saved as digital images, therefore, re-measurements are possible whenever it is necessary.

4. The images of bypass have been acquired with ground resolution of 2.5 cm (image resolution is 0.073 mm). Such resolution allows the identification of road surface details with high accuracy. Therefore, a semi-automated measurement approach allows accurate determination of surface distresses, such as potholes, ruts, etc. The measurement in images can be performed with accuracy up to 0.05 mm (15 mm on the ground).

5. The points positioning accuracy investigation in consideration with geodetic control measurements is determined. The average RMS for the points planimetric coordinates is 2.66 cm, and standard deviations – 2.50 cm; for the point's heights – 3.23 cm, 3.06 cm, respectively.

6. Fixing coincidence or mismatches of Vilnius western bypass project data with generated orthophoto using images from Unmanned Aerial Vehicle, the evaluation of relative accuracy shows not significant features discrepancies (the maximum – up to 5 cm).

7. The cost consideration of Unmanned Aerial Vehicle in conjunction with photogrammetry employment at experimental object is presented.

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