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PHOTOGRAMMETRIC MAPPING BASED ON UAV IMAGERY

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Abstract. Unmanned Aerial Vehicle (UAV) and Digital Photogrammetry is an up-to-date area mapping technology. Implemented features are low-cost, mobile and simple. UAV (fixed-wing *EPP-FPV*) with mounted digital camera (*Canon S100*) was used for imagery while digital photogrammetry processing (with *Lisa* software application) was applied for cartographic data collection. High imagery quality is a significant factor for the efficiency and quality of standard mapping products, such as Digital Elevation Model and Ortho Images. DEM and Orthophoto quality mainly depends on camera resolution, flight height and accuracy of Ground Control Points (GCP). In experimental investigations, GCP coordinates were gained interactively from the Internet. Application of the appropriate DEM checking technique showed that DEM error was up to 0.5 m.

Keywords: UAVs, autopilot, digital photogrammetry, image processing, DEM, orthophoto imaging, accuracy.

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Introduction

During a number of recent years, the use of unmanned aerial vehicles (UAVs) has increased significantly. Such activity can be ascribed to technical developments of electronic components and the possibility of their integration into remotely controlled aircrafts (Rock *et al.* 2011).

The term UAV is commonly used in the Artificial Intelligence, Computer Science and Robotics, as well as in the Photogrammetry and Remote Sensing communities. The new term *UAV Photogrammetry* describes a photogrammetric measurement platform, which operates remotely controlled, semiautonomous or fully autonomous without a pilot inside the vehicle. UAV photogrammetry opens various new applications in the close range domain, combining aerial and terrestrial photogrammetry. It is a new near real time application and low-cost alternative to the classical manned aerial photogrammetry (Eisenbeiß 2009).

Recently, digital aerial cameras have been used for image acquisition and nearly fully changed film based aerial cameras. The production of orthophoto and digital elevation models (DEMs) became completely digital, mostly automatic and with short response of time. These are the major factors ensuring success in gaining cartographic data from digital images.

The use of professional digital photogrammetric cameras demonstrates the benefits of digital image recording for terrain data generation by image matching. Elevation data from image matching are important for deriving cartographic data such as 3D building models and landscape visualization, roof shapes, canopy models, etc., as well as in generation and updating digital terrain models (Haala *et al.* 2010).

Digital photogrammetry methods are applied for generation of orthophotographic maps. For this purpose, needs to generate a digital terrain model of the Earth's surface and digital aerial image geometry correction, which removes geometric distortions due to tilt of the camera, the central projection and terrain effects. It is extremely important, that the digital terrain model of the Earth's surface would be created in the required quality for geometric transformation of digital images (Ruzgienė 2010).

The goal of investigations is to evaluate the quality of DEM generated using UAV photo images and to demonstrate application possibilities for cartographic data collection.

1. UAV performance and technical means

The fixed-wing UAV platform (model *EPP-FPV*) used for the image data acquisition is shown in Figure 1.

The *EPP-FPV* foam construction with a wingspan of 1.8 metres and a take-off weight around 4 kg makes it a robust, low cost, low weight UAV platform. The UAV has a cruising speed of about 14 m/s and is able to fly up to 30 minutes on low wind conditions. Therefore, it can cover a flight distance of roughly 30 km after subtracting some reserves for climbing and landing. Flight altitude can be very diversely, but is better of 150 m to 300 m, obviously of needed image resolution.

The platform guidance can be fully automatic, semi-manual or manual. Take-off is automatic or manual, landing on flat surface is automatic or manual. Autopilot *Ardu Pilot Mega* (APM) (see Fig. 2) is used for automatic guidance. It is based on the *Arduino* embedded system. Installed flight plan software *Mission Planner* allows a rather simple and fast guidance of the automated flight.

The UAV can be commanded by a PC based ground station, which is connected via RF link (Haala *et al.* 2011). Automatic flight needs a three axis gyroscope, three axis acceleration meter, pressure sensor, air velocity sensor, 10 Hz GPS module, battery voltage sensor, 4 Mb memory chip integrated flight parameter storage and a telemetry module (Rudinskas 2011).

Imagery has been taken using high-resolution consumer camera *Canon S100* (Fig. 3). Camera's nominal focal length is of 5.2 mm. Some camera features: a 1/1.7" CCD sensor, incorporated with 12,1 Mega pixels; integrated GPS module, that allows determining geodetic coordinates of each image projection centre during the flight. The maximum frame size of image is 4000 × 3000 pixels.

The camera was mounted under the airframe. Prior to a flight, camera is turn on, focus is determined as well as the focal length. The *Ardu Pilot* can operate not only UAV, but also other equipment located on the platform. The autopilot system is managing camera exposition; therefore, image collection is fully computer assisted. Obtained high-resolution images can be used for processing in a photogrammetry application (Sužiedelytė-Visockienė, Bručas 2009).

2. Image data acquisition

The universal workflow is accepted for image data acquisition:

– Determination of project parameters (PP).
– Flight planning (FP).

Fig. 1. Unmanned aerial vehicle used as the platform for acquisition of images

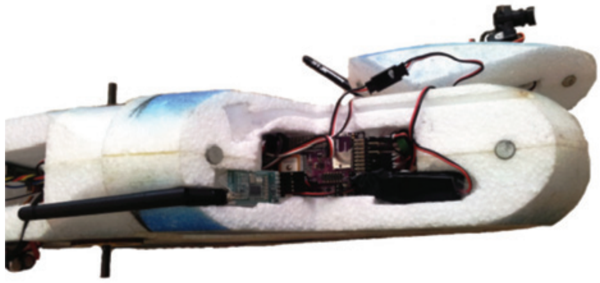


Fig. 2. *Ardu Pilot Mega* installation in UAV *EPP-FPV*

Fig. 3. Consumer camera *Canon S100* mounted at UAV

– Autonomous photogrammetric flight (APF).
– Quality check of the data (QCD).
– UAV Block Triangulation (UAV BT).
– Generation of Digital Surface Model (DSM), Orthophoto, 3D Model (DO3D).

During one autonomous photogrammetric flight, the UAV platform with the mounted camera can receive a collection of hundreds of images. The autonomous flight used the autopilot board and the PC software *Mission Planer*. This application uses a map (e.g., *Google Earth*), which is required for planning of a flight and signifying waypoints. It helps controlling autonomous triggering of images and autonomous take-off and landing. The producer proposed the following *Mission Planer* feature:

– Point-and-click waypoint entry, using *Google Maps*.

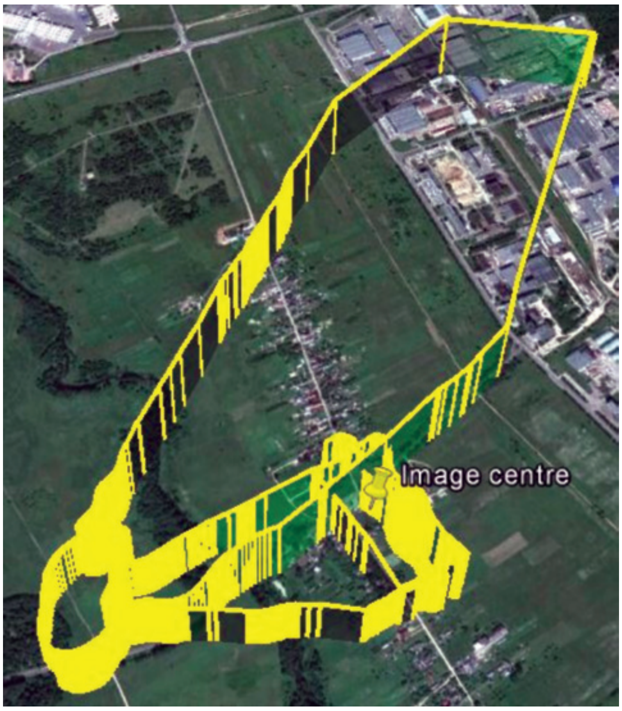


Fig. 4. Autonomous flight plan and area in *Google Earth* application

Fig. 5. Stereo pair (left and right) selected for photogrammetric image processing

- Select mission commands from drop-down menu.
- Download mission *log* files and analyse them.
- Configure APM settings for airframe.
- Interface with a PC flight simulator to create a full hardware-in-the-loop UAV simulator.
- See the output from APM's serial terminal.

Important features of the quality of the data checking is image resolution, clarity and tilts. After landing, collected images are checked; camera SD card is inserted into a PC for loading of images; if required, a flight is repeat. All jobs proceed in real time on the field.

Experimental flight using UAV *EPP-FPV* with equipped camera *Canon S100* was executed by employers from Space Science and Technology Institute (SSTI), Lithuania. Especially high requirements for flight realisation did not apply. The aim was to conduct a short flight and collect imagery. Planning of the flight depended on good weather, still wind and optimal altitude.

UAV flight was executed over the area of Naujakiemis, a region of Vilnius. The flight area (about 80 ha) was chosen purely accidentally. No different geomorphologic landforms were especially chosen as the focus was on the use of photogrammetric means for data capture. The site was partly flatlands with the mean altitude of approx. 125 metres.

After the manual take-off and check of the fixed-wing parameters, the flight mode was changed to the automated flying mode. When UAV take-off achieved the selected high, it began taking pictures. The UAV flight was controlled using the telemetry module; therefore, the density of waypoints was major near the telemetry module (Fig. 4). The flight path did not seem standard (not usual). The flight strips were generated as polygons of path and involved six polygons with gained 184 imageries.

The flights were performed at a height of approx. 150 m above the ground in order to capture images at a GSD (GSD = pixel size x H/c, H-flying height, camera focal length c = 35 mm, pixel size = 3 μm) of up to 10 cm.

3. Photogrammetric processing of images

Most software packages can process UAV images. UAV Block Triangulation – images oriented and generated by the navigation unit of the UAV, leads to a reduction of the number of control points required for the orientation. In terms of DSM, Orthophoto and 3D Model, commercial software packages and existing in house-developed tools are used. Photogrammetric processing software categorizes them into three classes based on their capability to process aerial, terrestrial and a combination of aerial and terrestrial data. Needs evaluation a selected software packages for UAV data processing and usage in applications (Eisenbeiß 2009).

Image pair has been selected for experimental investigations (Fig. 5).

The photogrammetric software package version of *LISA* has been used for image processing (Linder 2006). The package is divided into modules: *LISA BASIC, FOTO, BLUH* and *FFSAT*. The experiment used *LISA BASIC* and *FOTO*. *LISA BASIC* module is raster GIS software with numerous possibilities for image processing, terrain modelling, etc. *LISA FOTO* is the extension of *LISA BASIC* – a small digital photogrammetric workstation. The software package is of versions with slightly reduced functionality: the maximum size per image is limited to 10 MB, only grey scale (no colour) images can be processed. No tools to create and handle a data base for geocoded images are available.

The first step of preparatory works is dedicated to changing of image format to make it suitable for *LISA FOTO* and saving it as 8-bit greyscale photos. The following step is project definition using appropriate parameters (coordinates range, pixel size, etc.).

The ground control points (GCP) for exterior image orientation have been selected and coordinates defined interactively from the Internet using *www.maps.lt/*. Such approach was chosen because of minimal time required, no cost and not measuring on the field. GCPs was picked for features (e.g. base of electricity poles, well covers, building corners, etc.) that can be identified in images (Fig. 6).

For getting the best results for exterior image orientation, and because images from UAV are significantly under tilt, as many ground control points as possible are required (15 points were used). Accuracy of ground control point coordinates obtained from ortho-photo map meets the requirements of mapping at a scale up to 1: 10 000 (resolution of raster image is 0.5 m).

The results from image exterior orientation are presented in Figs 7 and 8.

The maximal residual in x and y coordinates for left image orientation is 0.073 mm referring to the image and the standard deviation is 0.055 mm; and for the right image — 0.158 mm and 0.084 mm, respectively. Image resolution is 180 dpi (141.1 μm), received residuals after exterior orientation are approx. of half a pixel.

Fig. 9 shows generated ortho-photo with overplayed contour lines (interval 5 m). The ortho-photo image covers about 35 000 m^2 area.

Fig. 6. Fragment of ground control point distribution on the test area

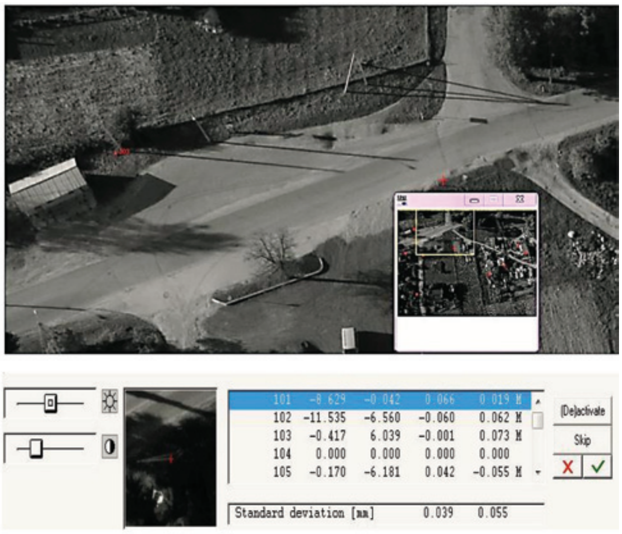
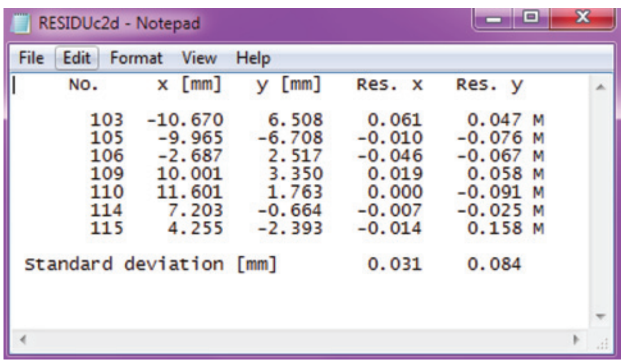


Fig. 7. Fragment of left image exterior orientation results



RESIDUc2d - Notepad

File Edit Format View Help

No.	x [mm]	y [mm]	Res. x	Res. y	
103	-10.670	6.508	0.061	0.047	M
105	-9.965	-6.708	-0.010	-0.076	M
106	-2.687	2.517	-0.046	-0.067	M
109	10.001	3.350	0.019	0.058	M
110	11.601	1.763	0.000	-0.091	M
114	7.203	-0.664	-0.007	-0.025	M
115	4.255	-2.393	-0.014	0.158	M
Standard deviation [mm]			0.031	0.084	

Fig. 8. Results of right image exterior orientation

Fig. 9. Ortho-photo with overlaid contour lines

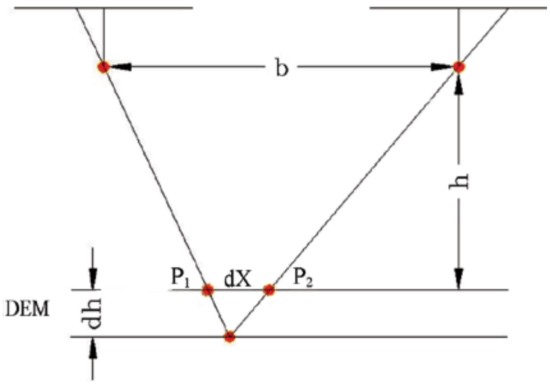


Fig. 10. Principle diagram for checking of digital elevation models

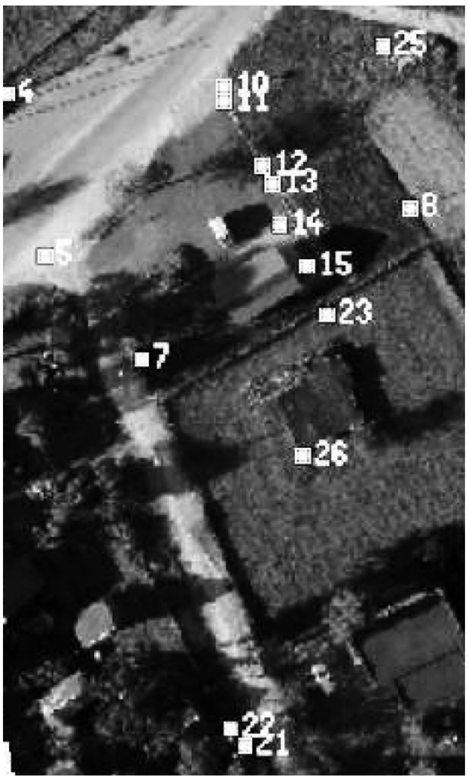


Fig. 11. Selected points for DEM evaluation

4. DEM evaluation

Digital terrain model (DTM) or digital elevation model (DEM) contains height values of terrain and needs for evaluation getting qualitative mapping product from images. DTM quality control involves interior and exterior accuracy. Interior accuracy can be defined by stereo measurements. Exterior accuracy – comparison created DTM's terrain point elevation with data from geodetic or GPS measurements.

The DEM can be improved when the measured height errors (*dh*) are determined and used as corrections (Norvelle 1996) (Fig. 10).

The errors of height in DTM are calculated using the following formula:

$$dh \approx dx\frac{h}{b}, \quad (1)$$

where dx – parallax between two images;

h – point height in DEM, $h = Z_{01} - Z_{DEM}$;

Z_{01} – elevation of left image projection centre;

Z_{DEM} – elevation of DEM point;

b – photo base.

Generated DEM (one dataset) from UAV images has been checked using the methodology described above.

Fig. 11 shows selected points for errors of heights calculation. Automatically from generated DTM, 3D points where imported regarding the measured 2D points coordinates.

DEM evaluation results are presented in Fig. 12. Maximal height error *dh* is 0.55 m. Generated terrain model should be corrected regarding determined height errors.

Conclusions

UAV Photogrammetry provides data used for image processing. Autopilot system guarantees correct flight, camera triggered auto-control. Geodetic coordinates of each image projection centre are available.

UAV Photogrammetry is a very promising technology that needs to be better investigated.

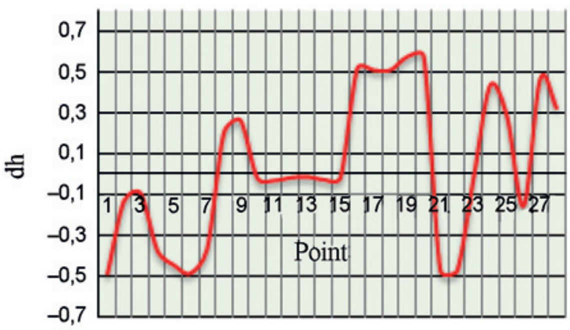


Fig. 12. Determined DEM height points error

The application of digital photogrammetric workstation *Lisa* is partially functional; therefore, it needs spatial software for UAV image processing and cartographic data collection.

Evaluation of DEM, generated from UAV images, demonstrates relevancy of digital elevation model correction aiming for a high accurate mapping product.

It can be stated, that UAV data is suitable for creation of 3D models of an area and meets the requirements for large-scale topography and GIS needs.

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