SURFACE MODELLING BASED ON UNMANNED AERIAL VEHICLE PHOTOGRAMMETRY AND ITS ACCURACY ASSESSMENT

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Abstract. Our study provides insight into modelling and assessment of a digital surface model of experimental plot. An unmanned aerial vehicle equipped with low-cost RGB camera was used. The camera system made it possible to acquire very high resolution imagery to generate ortho-mosaics and digital surface models through automatic 3D photo-reconstruction methods by Agisoft Photoscan solution. The unmanned aerial vehicle was operated manually by a pilot over the suggested study sites with concentrating to the problem of relief. The flight plan included across- and along-track overlaps (i.e. about 30 % and 60 %) using parallel flight lines. There were acquired 251 perpendicular images per 11.5 ha of the suggested plot, taken from an altitude of 50 m above the ground. Ortho-mosaic resolution in set height was 0.02 $m \cdot pixel^{-1}$. Registration to the coordinate system was done by ground control points (GCP) measured by the real-time kinematic global positioning system. In this purpose, 21GCP were surveyed. Over 24 million georeferenced points were used in the digital surface generation process. The resulting digital surface model was compared with various numbers of GCP used for orthophoto generation. Accuracy of the digital surface model with various numbers of GCP used was evaluated with the help of the Root Mean Square Error (RMSE) method. The RMSE value was 0.29m with the number of 21accuracy checkpoints measured by GPS in real-time kinematic mode per 11.5 ha.

Keywords: UAV, orthomosaic, ground control points, topographic surveying, DSM.

Introduction

Unmanned Aerial Vehicles (UAVs) are widely used in many applications for different purposes. In the past several years, UAV techniques have been developed and applied to agricultural applications. UAVs have begun to offer new alternatives for agriculture and other applications, in which high spatial resolution imagery delivered in near-real time is needed [1].

UAV photogrammetry is a photogrammetric measurement method, which uses remotely controlled, semiautonomous or fully autonomous vehicle without a pilot sitting in the machine [2]. UAV images have typical properties, which include higher radiometric homogeneity than either aircraft or satellite images due to the low altitude of acquisition [3]. The low altitude then results in a larger number of UAV images. With the large amount of images captured, image mosaicing is a necessary pre-processing step [4]. According to Gonzales et al. [5] and Luhmann et al. [6], the main photogrammetric procedures include – aerial triangulation, image orientation, model definition, creation of surface models, orthophoto generation, vector data collection for the geographic information system (GIS) or cartographic needs. Ruzgienė et al. [7] stated that the digital surface model (DSM) can be improved when to use a certain number of GCP and their coordinates determined by geodetic measurements. The GCPs are usually measured using the Real Time Kinematic Global Positioning System (RTK-GPS), e.g. [8]. These authors described two common methods for georeference data as well. The methods are direct and indirect. The direct method means that the 3D georeferenced point cloud can be generated directly, after the adjustment of the GPS time and the camera inertial time. The indirect methods include the GCP measuring before the flight by the method of RTK-GPS surveying. Vericat et al. [9] stated that the quality of image registration is highly dependent on the configuration of the GCP targets. The accuracy of the ortho-mosaicked image is dependent on the camera internal and external orientation, the density and distribution of GCPs and topographic complexity of the scene.

It is commonly known that topography plays an important role in agricultural assessment. Digital elevation models (DEM) or DSM were usually used to model various topographic attributes for agricultural purposes [10-12].

In this study the method for creating a detailed terrain model by using the 3D photo-reconstruction methods, where the UAV was used for collection of high density resolution photography, is presented. The detailed terrain model was compared with the reference measurements and the available terrain models.

Materials and Methods

The experimental data for this study were obtained from an experimental field of 11.5 ha in Prague-Ruzyne (50º05'N; 14°17'30"E), Czech Republic. The soil of this field is a Haplic Luvisol. The average precipitation is 526 mm per year and the average temperature is 7.9 ºC. Most of the field has a southern aspect and the elevation ranges from 338.5 to 357.5 m above average sea level (a.s.l.). The average slope of the field is approximately 6 %. Conventional arable soil tillage technology and fixed crop rotation were used on this field.

The UAV data set was acquired on 1st September 2015. The images of bare soil cover after winter oilseed rape sowing were obtained. Spring barley was the previous crop and it was harvested on 11th July 2015. We used consumer-grade RGB camera Sony NEX5 with fixed 16 mm focal length. The camera system was hanged at V-form octocopter platform AscTec Falcon 8 (maximum take-off weight of 2.3 kg), the camera angle of autonomous control was fixed at 90º. Both the UAV platform and camera system were manually controlled by a pilot. Parallel lines at around 50 meters above the area of interest were chosen, 60 % overlaid digital images at total count of 251 were acquired by this non-autonomous approach. This solution made it possible to acquire high resolution imagery necessary for generating orthomosaic and digital surface models (DSM) by stereo-photogrammetry based photo-reconstruction methods.

The PhotoScan 1.2.0 (Agisoft LLC, Russia) solution was used for processing the imagery. The main aim of processing the acquired images is to produce (a) very high resolution orthomosaic and (b)georeferenced point cloud, which is used for DSM generation. The images were aligned and rectified by 21 GCP, which were measured with sub-decimetre accuracy before the flight by RTK-GPS technology using the Trimble 5800 receiver with Trimble VRS Now corrections. GCP was designed as 0.5 m white numbered plates with the centered hole for survey rod. PhotoScan medium quality approach was used because of computing performance of a casual computer. More than half of million tie points were gained from the images, then high quality dense cloud was created for building orthomosaic and the digital surface model of the plot, see Table 1 for more details.

Table 1

Orthomosaic properties and DSM generating details

Property	Value
Area of interest	11.5 ha
Used images/GCPs	251/21
Gained tie points	587 252
Dense cloud points	24 972 526 (medium quality)
Orthomosaic/DSMoutput resolution	0.02/0.08 $m \cdot px^{-1}$

The digital surface model from UAV was compared with the RTK measured control points by GIS techniques using ArcGIS 10.3 (ESRI, USA). DSM derived from the UAV imagery was also compared with the Digital Surface Model of the Czech Republic of the 1st generation (DMP1G).

Results and discussion

Ortophoto-mosaic and the digital surface model were generated (Fig. 1). Total number of almost 25 million of dense cloud points were used. Very high resolution orthophoto-mosaic was gained – 0.02 $m \cdot px^{-1}$. Also high resolution surface model was created (0.08 $m \cdot px^{-1}$). Fig. 2 shows z values differences between the UAV based model and RTK based control points at each point. In spite of some critics [13], RMSE was calculated as an accuracy analysis. RMSE is a popular and very often used measurement of value differences from various data sets. RMSE of 0.29 m was calculated.

The quality of our generated outputs, the surface model above all, is influenced by many factors. Figure 3 represents decreasing surface elevation model quality towards plot borders. There are no equal image overlays for the plot and overlays were chosen just as 60 %. The numbers of UAV images are affected by high or dangerous object limitations. At the East border of the plot, there is beltway, therefore, data are missing because of not enough image overlaps at this part of the plot. The coverage of the area by images is evident from Fig. 1. If the image overlay decreases, the quality of the terrain model decreases as well. There are not enough overlaid images at the border parts of the plot also, so the quality of the generated elevation model is decreasing to the borders (Figure 3, border effect).

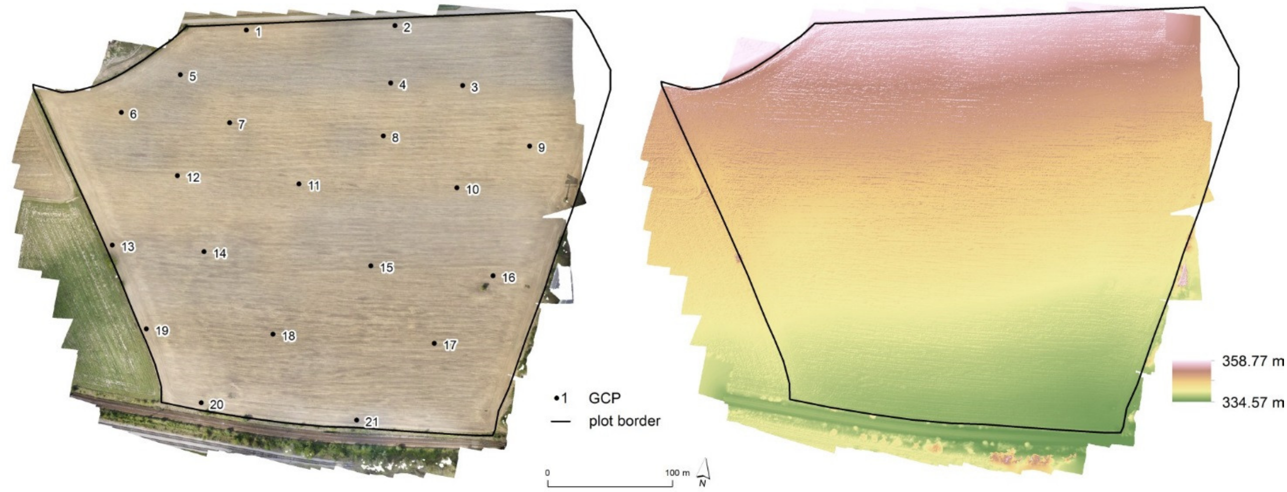

Fig. 1. **Orthophoto-mosaic and surface model generated from 251 images acquired from the UAV**

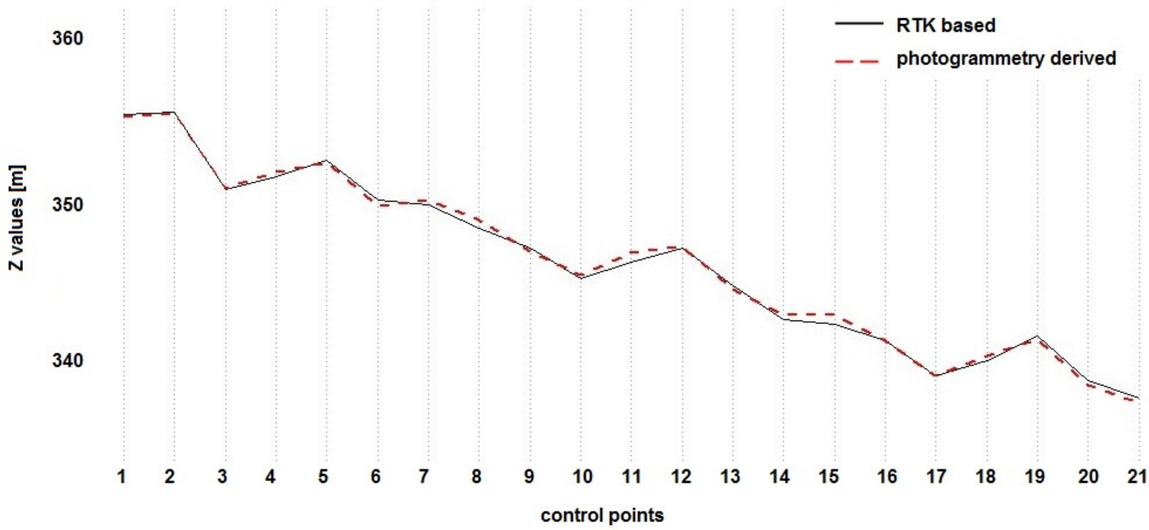

Fig. 2. **RTK based and photogrammetry derived (red dashed line) *z* values differences, total RMSE for 21 control points is 0.29 m**

DMP1G is the most accuracy surface model available for the Czech Republic, provided by the Land Survey Office of the Czech Office for Surveying, Mapping and Cadaster. Just mediumquality approach was used for generating outputs. Model DMP1G represents cover including any objects in irregular network form – TIN based, total standard error for not precisely limited objects (like forest and vegetation) is 0.7 m. Error differences are also affected by the DMP1G quality. On the other hand, the RMSE value presents half of the declared accuracy of the DMP1G terrain model.

Figure 4 represents a plot cut of detailed orthophoto-mosaic (a) and the digital surface mode (b). Aerial pictures with high density resolution enabled to prepare a very detailed terrain model, which brings an overview about the soil roughness, clodness and soil compaction caused by passes. Soil roughness reflects mainly management practices. It is possible to see turns of the tractor in Figure 4b. Soil micro-topography characterization and microvariations in surface elevation are an important issue for soil roughness descriptions. Soil roughness is influenced by many physical characteristics as water retention, infiltration, soil compaction [14; 15], and agronomical properties, like seed germination and emergence [16].

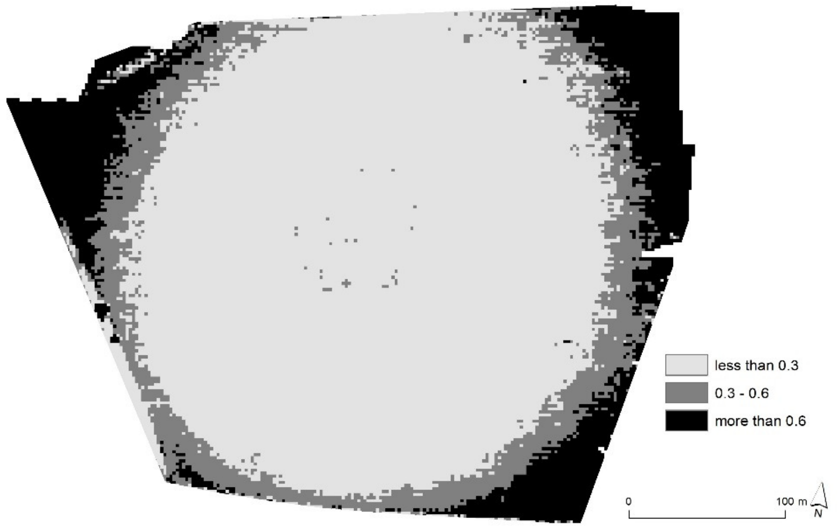

Fig. 3. ***Z* values difference (m), decreasing surface model quality towards plot borders**

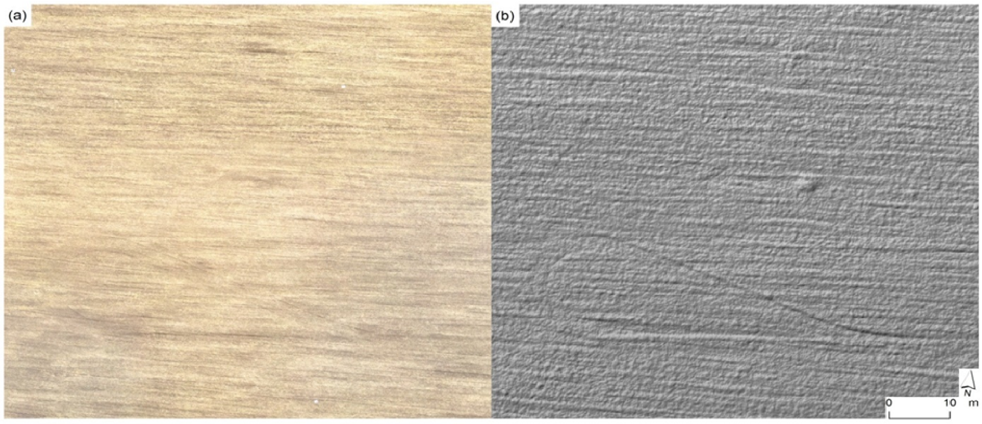

Fig. 4. **Orthophoto-mosaic (a) and DSM detail of surface (b)**

The advantage of these methods is based in nationwide sampling area of interest.This may constitute an appropriate supplement to mechanical methods [17] and optical methods of measurement, which were presented by Marinello et al. [18] or Aguilar [19].

Conclusions

The results showed that UAV photogrammetry can be used as a very efficient solution for generating high resolution orthophoto-mosaic and digital elevation (surface) models. Gaining imagery from unmanned vehicles is quite quick and operation of UAV is not expensive. It is possible to acquire very high resolution images of almost every area or object, with respect to particular rules and limitations, of course. It is clear from our results that the quality of outputs can depend on the number and quality of input images and image processing as well. We conclude that DMS based on UAV photogrammetry can be used for detecting of soil roughness and for improving of agriculture management from this reason.

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