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The Potential of UAV-Based Imagery and Structure from Motion with RTK and PPK Solutions for Mapping Accidental Areas

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Abstract— ***Combination of Unmanned Aerial Vehicle (UAV) - based aerial imagery and Structure – from – Motion (SfM) photogrammetry become a valuable tool that offers the capability of obtaining high-resolution images for a difficult and inaccessible area to be surveyed. This paper presents results obtained from different methods of georeferencing of UAV imagery using Real-Time Kinematic (RTK), and Post Processing Kinematic (PPK) for generation of Digital Terrain Model (DTM) and Orthomosaic for an area where the elevation difference is about 1100 m. A fixed-wing UAV equipped with a SODA camera were utilized for the corridor mode imagery. The study area were a corridor of (300 m) wide, and 22km length was covered by six flight missions in almost three hours. The Structure from Motion (SfM) technique was applied to create high-resolution 3D-models. The horizontal accuracy obtained from RTK and PPK solutions were (5.2) cm and (6.2) cm respectively; vertical accuracy were (13.2) cm and (14.9) cm for the RTK and PPK methods respectively. This study demonstrated that the RTK – based technique can provide accurate products than PPK method, despite the partially ground coverage by canopies. The results obtained may be considered adequate for mapping, of the area that can be used for other places because many such difficult and inaccessible regions are not yet surveyed in the region.***

Keywords: UAV, SfM, RTK, PPK, Orthomosaic, DTM

I. INTRODUCTION

The traditional survey methods, now adays are replaced by the UAV photogrammetry in more economical and less time consuming. In several fields of geosciences where unmanned aerial vehicles (UAVs) are deemed useful, rapid and precise direct georeferencing is becoming more important (Ekaso, Nex and Kerle, 2019) such as surveying and mapping, mining and quaries, construction, agriculture, environmental monitoring and emergency response. Using terrestrial surveying techniques to map accidental or risky areas is a challenging task (Tomaštík *et al.*, 2019).[1] In such situations, remote sensing methods may be useful and have been extensively used for this purpose ((Piermattei *et al.*, 2018; Matasci et.al 2018). [3]Ground Control Points (GCP) obtained by geodetic differential Global Navigation Satellite System (GNSS) receivers have traditionally been used to improve the georeferencing of UAV imagery (Gabrlik, Jelinek, and Janata 2016; Jóźków and Toth 2014; Kayitakire, Hamel, and Defourny 2006; [4]Neigh et .al 2014). The increasing use and advancement of digital photogrammetry approaches can be seen as part of the attempt to eliminate this dependence. Direct georeferencing can be used where GCP acquisition is affected by site problems or unsafe conditions, but also to improve surveying effectiveness. Without GCPs, the position and orientation of the exposure station of sensors are precisely determined to put UAV images in an Earth-Centered-Earth-Fixed (ECEF) coordinate system (Mostafa and Hutton 2001). The position and orientation of cameras could be accomplished by using high-quality GNSS and IMU devices integrated on the UAVs (Chiang, Tsai, and Chu 2012; Cramer et al., 2000; Mian et al. 2015) .[2]

Currently, a surface reconstruction tool combining SfM (Structure from Motion) photogrammetry and unmanned aerial vehicle (UAV) photogrammetry is available, providing DSM with extraordinary resolution at low cost (Westoby et.al 2012; Eisenbeiss, 2009). [14]The advent of Structure- from-Motion (SfM) and Multiview Stereopsis as a modern computer vision techniques, are makes RGB cameras to be utilized widely (Tomaštík *et al.*, 2019). The camera location and scene geometry was reconstructed using SfM. Its does not require a 3D location of the camera prior to image acquisition, unlike conventional photogrammetric techniques, so the position, orientation, and geometry are reconstructed using automatic matching of features in multiple images (Westoby et.al 2012). [5]

The aim of this study is to analyze the accuracy of photogrammetric products obtained individually from UAV based RTK and PPK techniques for accidental area covered partially by different types of canopies. The results were compared to the convetional terrstrail based measurements using geodetic global navigation satellite system (GNSS) receivers.

II. STUDY AREA

A corridor of 22 km length and width of 300 m is representing the study area. It is located 36 km east of Duhok

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Province, Kurdistan Region, Iraq, Figure 2.1. The proposed corridor is passing through an accidental area and crossing four mountains, forming approximately 71% of the corridor a bumpy terrain. This makes surveying impossible if traditional methods were used. Different types of canopy species partially cover the study area. The elevation varies along with the corridor's centerline between 450 m to 1550 m above mean sea level. Totaly (8) [13]Ground Control Points (GCPs) and 18 checkpoints (CPs) have been established along the route for accuracy analysis purposes. GCPs did not participate in the accuracy assessment; it's only used to measure 3D coordinates of the checkpoints.

Figure 2.1 Blue lines are study area; red triangles representing GCPs, blue circles are checkpoints

III. METHODOLOGY

The methodology consists of four phases (Figure 3.1)

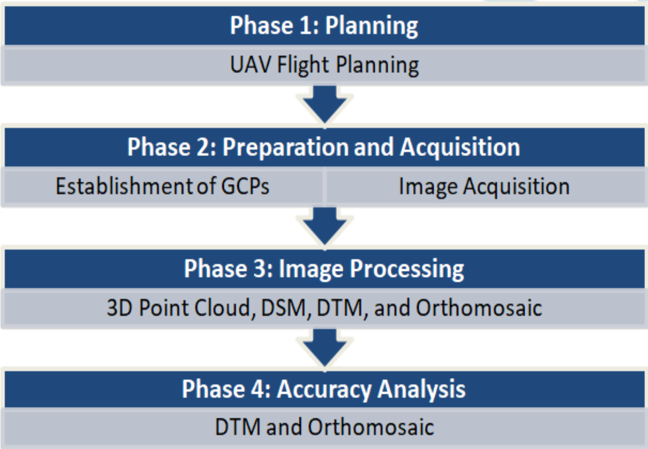

Figure 3.1 Road map of the research

3.1 UAV Flight Planning

Flight planning is performed by a software called eMotion 3, this will be accomplished in the office or in the field, the software requires the following entries: take-off and landing position of UAV, Ground Sampling Distance (GSD), flying altitude, forward and side overlap, focal length of camera, wind speed and its direction over the area.(fig 3.2).[12]

GSD = 4.0 cm per pixel, flying altitude = 170 m Above Elevation Data (AED), foreward and side overlap = 70%, focal length of the camera = 10.6mm, Sensor Optimized for Drone Application (S.O.D.A.) digital camera of 20 mega pixel resolution used. Number of flight lines were 318 at 66m spacing , grond coverage of (219 x 146 m) obtained.[15]

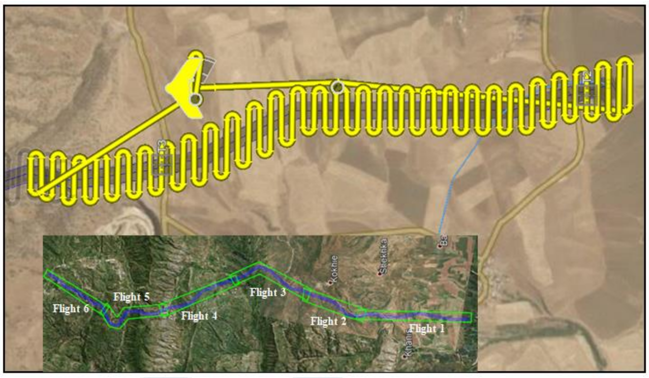

Figure 3.2 Yellow lines representing flight 1, green polygons are six flight plans.

3.2 Preparation and Acquisition

Totally, eight Ground control points (GCPs) were established along the corridor and at the UAV image coverage boundaries at different elevations (*8* GCPs spaced at the 2.5 km interval) to achieve desired georeferencing accuracy. The XYZ location of each GCP marker was determined using the Leica Viva GNSS. The study area's UAV images were collected within (3 hours) for (6 flights) successively by SenseFly eBee PLUS fixed-wing UAV. The UAV was equipped with an autopilot and navigation GPS and IMU. At each flight, the base station occupied by the GPS receiver for real-time positioning.

Particularly, (938)[6] images were captured through flights 1, 2, and 3 by utilizing RTK technique, to cover (10 km) corridor route along the study area. Other (903) images were acquired through flights 4, 5, and 6 using PPK technique, to cover the remaining part (11.0 km) corridor route of the study area. The total collected images for both RTK and PPK methods are (1841). [7]

3.3 Image Processing

The automated computer vision Structure from Motion (SfM) provided by Pix4Dmapper software package was used for data processing. Two image data sets based on RTK and PPK techniques were separately processed. Pix4Dmapper software processes digital images in three main stages:

1- Initial processing, input image data of (938 for RTK and 903 for PPK) of the study area were uploaded without contribution of GCPs data to perform the followings:
   - Keypoint exraction, identification and determination of locations of well defined points as keypoints in the images.
   - Keypoint matching, the same keypoints are matched in the neighbouring images.
   - Camera calibration (internal and external)parameters are calculated.
   - Georefencing.

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The out put of initial processing is Automatic Tie Points.

2- Point Cloud and Mesh generation, depending upon Automatic Tie Points (figure 3.3):
   - Point Cloud Densification, additional tie points are created based on the Automatic Tie Points, that will result a densified cloud points .
   - 3D textured mesh creation depending on the densified cloud points.

3- Output, the software will create DSM, DTM, Orthomosics

Figure 3.3 generated dense point cloud from Pix4Dmapper

3.4 Accuracy Analysis

The 3D coordinates of check points defined by 18 photogrammetric targets were measured directly on the field using RTK technique of Leica Viva GS15 GNSS receiver considering GCPs as a reference points. In the other hand, generated digital terrain model (DTM) and orthomosaic were exported into the Global Mapper software, then horizontal and vertical coordinates were extracted of the 18 check points (9 for RTK and 9 for PPK) [9]appeared on the produced orthomosaic. Extracted coordinates was stored in the test format and then exported into the MS-Excel for further assessment. Generally, 18 check points have been categorized into the RTK and PPK datasets. Their measured coordinates from photogrammetric products were compared to the reference coordinates acquired directly from the field. Root Mean Square Error (RMSE) was utilized for comparison and evaluation.

$$RMSE_E = \sqrt{\frac{\sum \Delta E^2}{n}} \quad (1)$$

$$RMSE_N = \sqrt{\frac{\sum \Delta N^2}{n}} \quad (2)$$

$$RMSE_Z = \sqrt{\frac{\sum \Delta h^2}{n}} \quad (3)$$

$$RMSE_{EN} = \sqrt{{RMSE_E}^2 + {RMSE_N}^2} \quad (4)$$

Where ΔE , ΔN and ΔZ representing the differences between the actual and measured coordinates from photogrammetric products (DTM and orthomosaic), n is the number of points in the dataset, $RMSE_{EN}$ is the horizontal accuracy criteria, $RMSE_Z$ is the elevation accuracy criteria.

IV. RESULTS AND DISCUSSION

Positional accuracy of the generated orthomosaic was assessed using Global Mapper software by demarkation of the appeared centers of targets of the check points (CPs). Height coordinates were acquired on the produced DTM through extraction tools available in the Global Mapper software. Positional and vertical root mean square errors (RMSE) for RTK and [8]PPK technique datasets were computed based on the reference coordinates and statistical analysis, Table 1 and 2.

Table 1. Positional root mean square errors ($RMSE_{EN}$) for CPs

Technique	$RMSE_E$ (m)	$RMSE_N$ (m)	$RMSE_{EN}$ (m)	Mean	n
RTK	0.042	0.031	0.052	0.039	9
PPK	0.051	0.036	0.062	0.043	9

Table 2. Vertical root mean square errors ($RMSE_Z$) for CPs

Technique	$RMSE_Z$ (m)	Mean	n
RTK	0.132	0.140	9
PPK	0.149	0.115	9

In general, GCPs with 1.0 cm level of accuracy obtained from static observation were not contributed directly into the image processing for georeferencing purpose. Although they served as a reference (base) to compute GNSS corrections necessary for RTK flights, also their accurate coordinates utilized as a reference coordinate during downloading PPK flights. Hence the influence of GCPs is not presented in the accuracy analysis.[10]

Higher the accuracy lowest RMSE results were obtained by the RTK method compared to the PPK technique Figure 4.0. Overall, the errors from RTK -based method were lower than PPK-based technique. Horizontal errors ($RMSE_{EN}$) of RTK approach did not exceed (5.0) [11]centimeters. While it's vertical accuracy ($RMSE_Z$) of (13.2) centimete. Obviously, both RTK and PPK solutions significantly not influenced to accuracy degradation due to presence of vegetation and canopies over the study area.

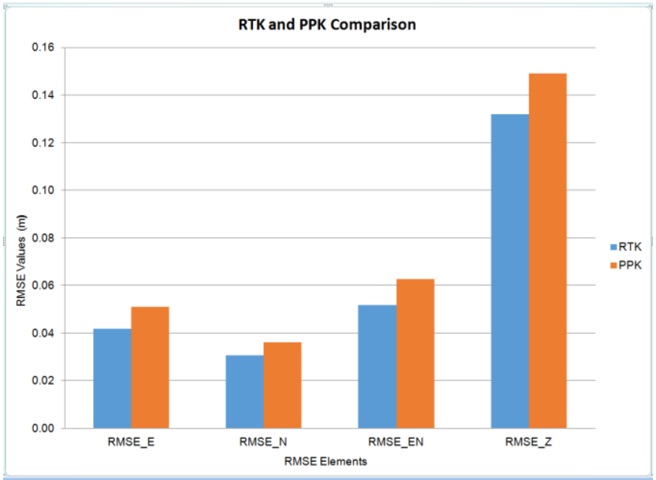

Figure 4.1 Histogram of horizontal and vertical RMSE of RTK and PPK datasets

V. CONCLUSION

In this study, the potential of RTK and PPK solutions in the accidental areas partially covered by the different types of canopies was investigated. High quality of UAV-based geospatial data was obtained without contribution of GCPs for georeferencing. Photogrammetric products were analyzed and compared with the referenced data. The results of both RTK and PPK methods were more accurate regardless of the impact of georeferencing with GCPs. Overall, horizontal and vertical RMSEs of the (5.0) cm and (11.5) cm of the RTK-based Orthomosaic and DTM were accurate than products of PPK approach. Due to robustness of the SFM algorithm powered by Pix4Dmapper software, the accuracies of both RTK and PPK not influenced by the canopies partially covered the study area. Some of the limitations of the study included the choice of the optimal locations for GCPs for verifications due to the dense forestry. The results showed that UAV photogrammetry can be applied for mapping accidental terrain more economically, and less time required.

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