Available online at www.humg.edu.vn

ESASGD 2016

GIS-IDEAS (2016)

Conference Title: International Conference on GeoInformatics for Spatial-Infrastructure Development in Earth & Allied Sciences (GIS-IDEAS)

A solution improving the horizontal precision for images captured Unmanned Aerial Vehicles (UAV)

Nguyen Huu Nhat[a,b], Le Van Trung[a,b], Nguyen Tan Luc[a], Le Trung Chon[a]

Ho Chi Minh City University of Technology, Viet Nam
Geomatics Center, VNU-HCM, Viet Nam

Abstract

This paper proposes a solutions to improve the horizontal precision for the ortho-mosaic images which are processed by Pix4Dmapper software for the images dataset captured by the Unmanned Aerial Vehicles (UAV) system. We use Helmert transformation to transform from the coordinate system of ortho-mosaic images to the local coordinate system through ground control points (GCPs), then we assess accuracy of the ortho-mosaic images through GCPs surveyed by Total Station. The results, when using Helmert transformation the horizontal precision to increase five fold compared with the image processing method that uses GCPs and to increase seven fold compared with the image processing method that not uses GCPs. In addition, we also compared between the two digital elevation models: LiDAR model and DSM model for the same area at the same time (DSM model is created from the images dataset captured by the UAV system). The results, the DSM model is quite consistent with the LiDAR model, the different height error averaged 1.2cm. With this result, the UAV technology can be applied to established large scale topographic map instead of the traditional method.

Keywords: UAV, Helmert transformation, Pix4Dmapper, DSM, LiDAR

1. Introduction

In [1], UAV AscTec Falcon 8 system (Fig. 1) was used to monitoring the progress of construction works of urban rail project, HCMC. The UAV system acquired high-resolution images at the different stages of the project. UAV AscTec Falcon 8 system could operate flexibly and effectively to capture images when flying at low height. In addition, we used the Pix4Dmapper software for image processing to create orthoimage, DSM model, 3D model based on the coverage of the images.

To develop and expand UAV applications in mapping, especially high-ratio map, we investigated and then proposed solutions to improve the accuracy of ortho-images using UAV. We used Ground Control Points (GCPS) as gold standard to assess the accuracy of ortho-image map. We used Helmert transformation algorithm to improve this accuracy. In addition, we also compared elevation between DSM models and LiDAR model.

This study shows the feasibility of the application of UAV systems to capture aerial photos with high resolution and high spatial (ground and altitude) accuracy. UAV systems can be used to establish large scale topographic map and monitor the progress of construction works over time.

* Corresponding author. Tel.: +84838637318 E-mail address: ltchon@hcmut.edu.vn

Fig. 1 UAV (Falcon 8) and facilities used for aerial photography

2. Experiment and Data Processing

2.1. Experiment

Two areas were chosen for experiments, evaluating the accuracy of the horizontal and vertical data as follows:

- The depot with an area of 27.7 ha in metro projects 1 (line Ben Thanh - Suoi Tien, HCMC) (figure 2a) was chosen to evaluate the accuracy of horizon;
- Area of Station 2 in Thu Duc district, HCMC (figure 2b) is selected to build DSM taken by images from and compare this model with DSM built by LiDAR data (provided by DOST) with the same time.

Fig 2. (a) Depot area *(b) Station 2 area*

2.2. Data collection

With the help of these flight plans the UAV is steered autonomously over predefined routes. Along these paths aerial images are taken at 100m for altitude, the overlap along track (flight direction) and the overlap across track are shown in the table 1.

Table 1. Parameters of designed flights

Area	Resolution (cm)	Altitude (m)	Coverage of y-axis (%)	Coverage of y-axis (%)	Number of images
Depot	2.9	100	70	55	181
Station 2	2.9	100	85	80	66

There are 15 ground control points (GCP) on the depot marked on in the field before capturing flight, to ensure they are visible in the captured image. Coordinates of these GCP measured by total station, including 01 of grade IV and 14 points of 2nd degree of traverse. 10 points of them are used for Helmert tranformation (P02, P04, P05, P06 , P08, P10, P11, P13, P14, P15 with yellow square) and 5 points are used to evaluate the accuracy of this method (P01, P03, P07, P12, P16 with red circle). (fig 3a, 3b).

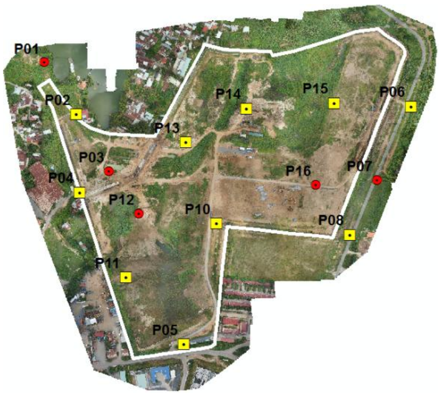

Fig. 3. (a) GCP distribution on the depot *(b) GCP on images*

2.3. Data processing

All processed data were in VN2000 datum (with central meridian 105^{0}45', scale factor of central meridian k=0.9999) and MSL in Hon Dau, Hai Phong.

The Gaussian formular was used evaluating the accuracy of ortho-images processed by Pix4Dmapper software based on GCPs.

Horizontal mean squared error is determinate by formulae:

$$m_P = \sqrt{m_x^2 + m_y^2} = \sqrt{\frac{\sum_{i=1}^{n}\left(x_i - x_i^0\right)^2 + \sum_{i=1}^{n}\left(y_i - y_i^0\right)^2}{n}} = \sqrt{\frac{\sum_{i=1}^{n}\Delta s_i^2}{n}} \qquad (1)$$

With:
- x_i^0, y_i^0 - coordinate of ith point measured by total station;
- x_i, y_i - coordinate of ith point deteminated by processed ortho-images;
- n – number of GPC used evaluating the accuracy

Helmert transformation is used to change coordinates of GCPs in ortho-images from WGS84 to VN2000

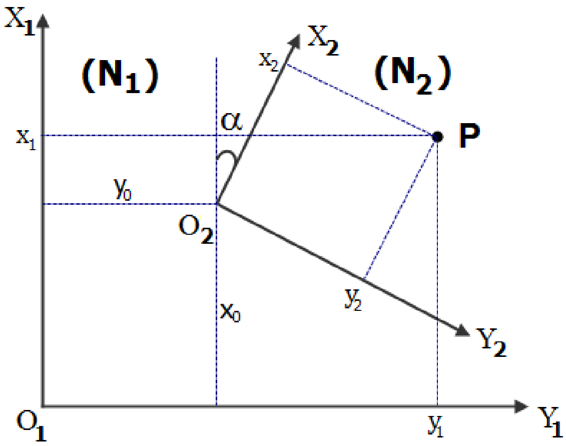

Fig 4. Helmert transformation

$$\begin{pmatrix} x_2 \\ y_2 \end{pmatrix} = \begin{pmatrix} x_0 \\ y_0 \end{pmatrix} + m\begin{pmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{pmatrix}\begin{pmatrix} x_1 \\ y_1 \end{pmatrix} \qquad (2)$$

With
- x_0, y_0: origins of 2nd system *(N_2)* in 1st system *(N_1)*;
- α: rotation angle of (N_2)to (N_1);
- m: scale factor of of (N_2)to (N_1).

Setting $\begin{array}{l} p = m\cos\alpha; \\ q = m\sin\alpha, \end{array}$ and $\begin{array}{l} \alpha = \arctan\dfrac{p}{q}; \\ m = \sqrt{p^2 + q^2} \end{array}$

Rewrite (2): $\begin{pmatrix} x_2 \\ y_2 \end{pmatrix} = \begin{pmatrix} x_0 \\ y_0 \end{pmatrix} + \begin{pmatrix} p & -q \\ q & p \end{pmatrix}\begin{pmatrix} x_1 \\ y_1 \end{pmatrix}$ *(3)*

To determinate transformation parameters from (N_1) to (N_2), at least 2 coinciding points are required and least squared method is used deteminating these parameters:

$$A^T AX - A^T L = 0, \quad (4)$$

With:

$$A_{(2n\times4)} = \begin{bmatrix} 1 & 0 & x'_{11} & -y'_{11} \\ 1 & 0 & x'_{12} & -y'_{12} \\ . & . & . & . \\ 1 & 0 & x'_{1n} & -y'_{1n} \\ 0 & 1 & y'_{11} & x'_{11} \\ 0 & 1 & y'_{12} & x'_{12} \\ . & . & . & . \\ 0 & 1 & y'_{1n} & x'_{1n} \end{bmatrix}; \quad L_{(2n\times1)} = \begin{bmatrix} x_{21} \\ x_{22} \\ \cdots \\ x_{2n} \\ y_{21} \\ y_{22} \\ \cdots \\ y_{2n} \end{bmatrix}; \quad X_{(4\times1)} = \begin{bmatrix} x_0 \\ y_0 \\ p \\ q \end{bmatrix}$$

Solving equation (4), transformation parameters are determinated $X = \left(A^T A\right)^{-1} A^T L$

Three versions of image processing are used:

i. without using GCPs to manipulate images by Pix4Dmapper;
ii. using GCPs to manipulate images by Pix4Dmapper;
iii. applying Helmert transformation to ortho-images

3. Analyse result

3.1 The accuracy of horizontal coordinates

Using Pix4Dmapper without GCPs, ortho-images were created in WGS84 and changed to VN2000 by 7 coordinate transformations (provided by MONRE). The results are showed in table 2

Table 2. Evaluating the horizontal accuracy with GCPs

No	ID	On ground		On image (with GCPs)		Δx^2	Δy^2	Δs^2
		x_0 (m)	y_0 (m)	x (m)	y (m)			
1	P01	1203548.882	616682.017	1203549.081	616682.057	0.0395	0.0016	0.0411
2	P02	1203438.647	616750.239	1203438.720	616750.334	0.0053	0.0090	0.0143
3	P03	1203316.657	616820.411	1203316.692	616820.459	0.0012	0.0023	0.0035
4	P04	1203271.661	616756.804	1203271.645	616756.874	0.0003	0.0049	0.0051
5	P05	1202948.310	616980.239	1202948.036	616980.322	0.0752	0.0068	0.0820
6	P06	1203455.147	617465.930	1203455.109	617466.444	0.0014	0.2638	0.2652
7	P07	1203298.181	617393.232	1203298.070	617393.703	0.0122	0.2217	0.2340
8	P08	1203181.879	617334.679	1203181.683	617335.123	0.0382	0.1974	0.2357
9	P10	1203205.747	617050.040	1203205.622	617050.299	0.0156	0.0671	0.0827
10	P11	1203090.879	616856.047	1203090.740	616856.158	0.0192	0.0122	0.0314
11	P12	1203226.792	616884.688	1203226.719	616884.774	0.0054	0.0075	0.0129
12	P13	1203378.550	616984.061	1203378.560	616984.314	0.0001	0.0641	0.0642
13	P14	1203450.880	617114.462	1203450.918	617114.806	0.0014	0.1187	0.1201
14	P15	1203462.388	617301.422	1203462.397	617301.850	0.0001	0.1831	0.1832
15	P16	1203287.760	617262.736	1203287.703	617263.114	0.0032	0.1425	0.1458

Then least square error is: $m_P = \sqrt{\frac{\sum_{i=1}^{15} \Delta s_i^2}{15}} = 0.3185m$

In the case using GPCs to process, the results are showed in table 3

Table 3. Evaluating the horizontal accuracy with GCPs

No	ID	On ground		On image (without GCPs)		Δx^2	Δy^2	Δs^2
		x_0 (m)	y_0 (m)	x (m)	y (m)			
1	P01	1203548.882	616682.017	1203549.053	616681.993	0.0292	0.0006	0.0298
2	P02	1203438.647	616750.239	1203438.753	616750.245	0.0113	0.0000	0.0114
3	P03	1203316.657	616820.411	1203316.689	616820.344	0.0010	0.0045	0.0055
4	P04	1203271.661	616756.804	1203271.634	616756.686	0.0007	0.0140	0.0147
5	P05	1202948.310	616980.239	1202948.238	616980.345	0.0052	0.0113	0.0166
6	P06	1203455.147	617465.930	1203455.000	617465.881	0.0217	0.0024	0.0241
7	P07	1203298.181	617393.232	1203298.275	617393.090	0.0088	0.0203	0.0291
8	P08	1203181.879	617334.679	1203182.061	617334.701	0.0331	0.0005	0.0335
9	P10	1203205.747	617050.040	1203205.835	617050.139	0.0077	0.0097	0.0175
10	P11	1203090.879	616856.047	1203090.853	616856.176	0.0007	0.0165	0.0172
11	P12	1203226.792	616884.688	1203226.686	616884.727	0.0113	0.0016	0.0128
12	P13	1203378.550	616984.061	1203378.529	616984.174	0.0004	0.0129	0.0133
13	P14	1203450.880	617114.462	1203450.856	617114.578	0.0006	0.0136	0.0142
14	P15	1203462.388	617301.422	1203462.194	617301.506	0.0378	0.0071	0.0448
15	P16	1203287.760	617262.736	1203287.774	617262.818	0.0002	0.0067	0.0069

And least square error is: $m_P = \sqrt{\frac{\sum_{i=1}^{15} \Delta s_i^2}{15}} = 0.1908m$

Using 10 GCPs and (4) to determinate Helmert transformation parameters, these parameters are $x_0 = 739.0205; y_0 = 428.2681; p = 0.9994$ and $q = -0.0002$. The remain GCPs were recalculated by using Helmert formulae with these parameters

Table 3. Evaluating the horizontal accuracy with Helmert transformation

No	ID	On ground		By Helmert		Δx^2	Δy^2	Δs^2
		x_0 (m)	y_0 (m)	x (m)	y (m)			
1	P01	1203548.882	616682.017	1203548.901	616681.984	0.0004	0.0011	0.0015
2	P03	1203316.657	616820.411	1203316.684	616820.346	0.0008	0.0042	0.0050
3	P07	1203298.181	617393.232	1203298.188	617393.236	0.0001	0.0000	0.0001
4	P12	1203226.792	616884.688	1203226.780	616884.639	0.0001	0.0024	0.0025
5	P16	1203287.760	617262.736	1203287.802	617262.731	0.0017	0.0000	0.0017

And least square error is: $m_P = \sqrt{\frac{\sum_{i=1}^{5} \Delta s_i^2}{5}} = 0.0464m$

The deviation between ground coordinates and the coordinates calculated by 3 methods is presented in following chart (fig. 5)

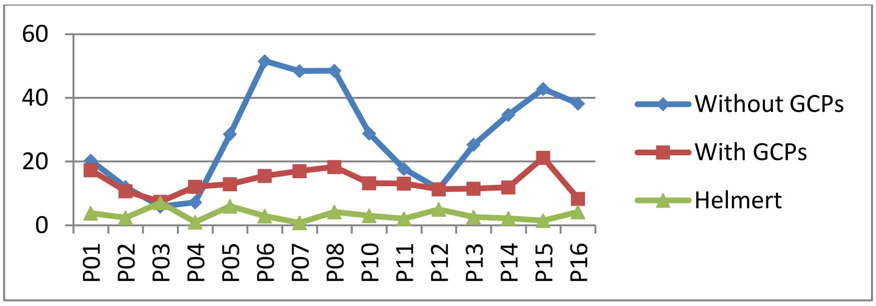

Fig 4. Chart of the deviation between ground coordinates and the calculated coordinates

From this chart, using Helmert transformation for manucipating ortho-images can improve the accuracy of horizontal coordinates to at least 5 times.

3.1 The accuracy of elevation

The DSM created by Pix4Dmapper (called DSM-P) for Station 2 area is compared with LiDAR data in the same time.

Fig 5. Ortho-image at Station 2 area

(x_{1i}, y_{1i}, h_{1i}) and (x_{2i}, y_{2i}, h_{2i}) are horizontal coordinates and elevation of concoide i^{th} point in LiDAR date and DSM-P data, then elevation deviation of this point is calculate by following formular: $\Delta h_i = h_{2i} - h_{1i}$

The mean of elevation deviation between LiDAR and DSM-P is $\bar{\Delta h} = \frac{\sum_{i=1}^{n} \Delta h_i}{n}$

And standard deviation is $\sigma_{\Delta h} = \sqrt{\frac{\sum_{i=1}^{n} \Delta h_i^2}{n}}$

With probability of 95% (t=2), 28050 points were chosen to compare and result are is shown in fig. 6.

The mean of elevation deviation is $\Delta \bar{h} = 0.012m$ and standard deviation is $\sigma_{\Delta h} = 0.166m$

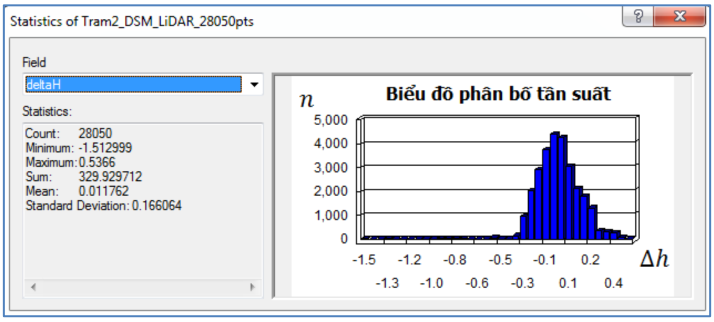

Fig. 6 Statistic of elevation deviation between DSM-P and LiDAR

Surfer software is used to creat DSMs from DSM-P and LiDAR data. These DSMs are shown in fig 7 and two models is suited each other with quite small deviation.

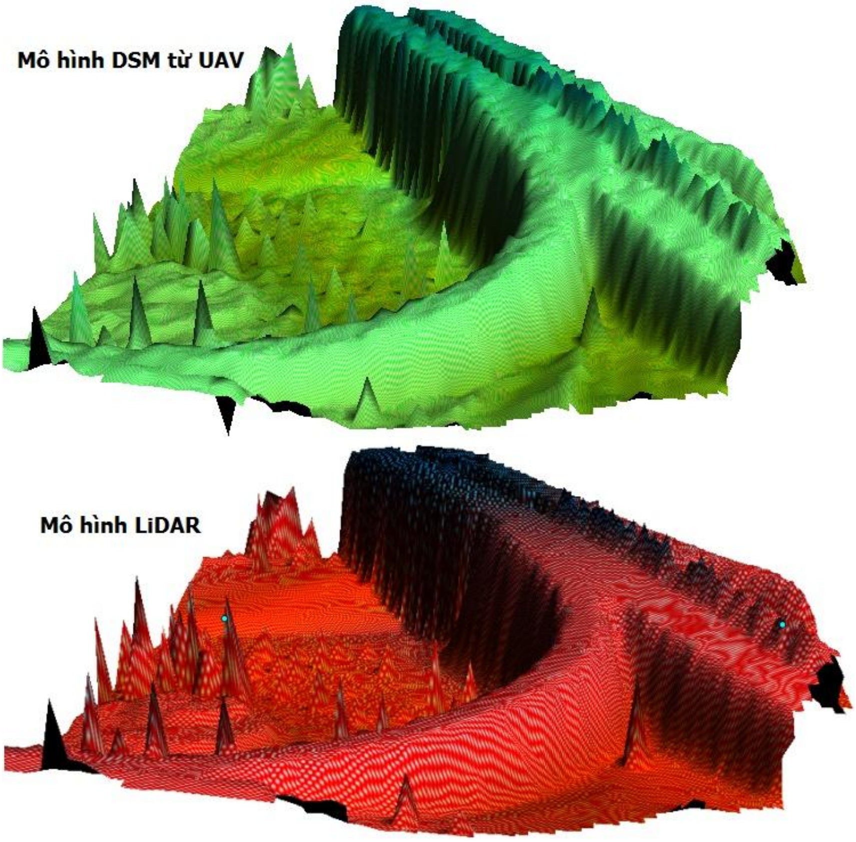

Fig 7. The 3D model build from UAV and LiDAR data

4. Conclusion

Using Helmert transformation to change ortho-images from WGS84 to VN200 can improve the accuracy of horizontal coordinate to 5 times in case of with GCPs and to 7 times without GCPs. With this accuracy, UAV can be used to capture and make topographical map with 1:500 scale. In addition, DSM created by images captured from UAV can trust. This opened a new feasible application when building a DSM for a small area (an area of a few hundred hectares), UAV can be used to reduce cost and implementation time.

References

Lê Trung Chơn et al, *Using Unmanned Aerial Vehicles (UAV) for mornitoring construction progress of Ho Chi Minh City urban railway project*. Journal of Science and Technology, Vol 18, No.K3- 2015, pp. 105-113

Küng O, Strecha C, Beyeler A, Zufferey J.-C., and Floreano D, "The Accuracy of Automatic Photogrammetric Techniques on Ultra-light UAV Imagery," in *AV-g 2011 - Unmanned Aerial Vehicle in Geomatics*, Zürich, September 2011, pp. 14-16

Rijsdijk M et al, "Unmanned aerial systems in the process of juridical verification of cadastral borders," in *UAV-g 2013 - Unmanned Aerial Vehicle in Geomatics*, Rostock University, Germany, September 4-6, 2013.

Cục Đo đạc Bản đồ nhà nước, *Quy phạm đo vẽ bản đồ địa hình tỷ lệ 1/500, 1/1000, 1/2000, 1/500.* Hà Nội, 1990