Analysis of Horizontal Accuracy for Large Scale Rural Mapping Using Rotary Wing UAV Image

Husnul Hidayat*, Bangun Muljo Sukoko
Department of Geomatics Engineering, ITS, Surabaya
hidayat@geodesy.its.ac.id

Abstract. In order to fulfil the need of large scale map for rural mapping, Indonesian government is now looking for alternatives of geospatial data sources. With newly developed technology, nowadays rotary wing UAV can be used to acquire very high resolution aerial imagery quickly with low cost. This research assesses the horizontal accuracy of rural mapping in 1:2000 scale using orthophoto derived from rotary wing UAV image data. The test site of this research is Kebonwaris village, Pandaan, East Java which has an area of approximately 167 hectares. Image data was taken with approximately 80% overlap each other and processed using Structure from Motion approach. Twelve GCPs coordinates were measured using differential GPS observations for georeferencing purpose. For accuracy assessment, 22 test points were established and their coordinates were measured using static differential GPS observations. The results show that the mean absolute horizontal errors are 0.071 m and 0.142 m for easting and northing respectively and the Root Mean Square Errors are 0.088 m and 0.169 m for easting and northing respectively. These RMSE values represents horizontal RMSE 0.190 m. According to Peraturan Kepala BIG No. 15 Tahun 2014, this RMSE value represents the 0.289 m horizontal accuracy based on CE90 criterion. Therefore, with this level of accuracy the UAV image data can be used to make a class 1 base map in 1:2500 scale or class 2 base map in 1:1000 scale.

Keywords: UAV, rural, accuracy, mapping

1. Introduction
1.1. Background
Indonesian government is now seeking for alternatives of geospatial data acquisition for rural mapping. On the Undang-undang Nomor 14 Tahun 2014 Pasal 8 Ayat 3 states that the location and administrative boundary of a village must be shown in the form of rural or village map. Currently the most detailed official topographic map released by Badan Informasi Geospasial (BIG, Geospatial Information Agency) are available only in 1:10000th scale. On the other hand, Peraturan Kepala BIG Nomor 3 Tahun 2016 [1] states that the rural map must be presented in 1:2500th, 1:5000th, or 1:10000th scale according to the total area and boundary extent of the village. Since the size of many villages are varying, for small villages there are no data for producing any map with 1:2500th or 1:5000th scale.

An alternative for this problem is high resolution optical satellite imagery. But in reality this image is not cloud-free at all, mainly in tropical region which is prone to rain. Besides that, the generated image is not truly orthographic imagery mainly in hilly and mountainous region. This effect is known as relief displacement and can only be corrected by using Digital Elevation Model (DEM) data. Nowadays the
worldwide available DEM data is only in 30-meter resolution which is not accurate for correcting optical imagery with submeter resolution.

Recent development in robotic and automation technology have widened the possibility of large scale photogrammetric mapping using Unmanned Aerial Vehicle (UAV). The UAV can be defined as any aerial platform which can be operated without a pilot sitting in it. This platform can be remotely controlled or fly autonomously with preprogrammed flight trajectory [2]. One advantage of UAV image data is the ability to extract topographic information along with land cover information. This platform is effective for mapping an area less than 1000 ha [3]. This platform has been used in many ways, such as disaster monitoring [4][5], archaeological documentation [6][7][8], and high accuracy topographic mapping [9][3].

1.2. Problems
One type of popular UAV is rotary wing UAV. This platform is more preferred due to ease of use, great manoeuvrability, and its ability to take off without special runway. But main the drawbacks of this platform are limited operational range which requires more flight and limited payload. Most of consumer-grade UAV are equipped with small format nonmetric camera which have lower image quality compared to metric camera image. Therefore, the final product of orthophoto derived from UAV images must be assessed mainly in horizontal accuracy. This accuracy test is fundamental to determine the scale of the most detailed map which can be derived from this type of imagery.

The main problems of this research is how to create orthophoto mosaic from rotary-wing UAV image data and assessing its horizontal accuracy for large scale map production. The study location is limited only in Kebonwaris Village, Pandaan, East Java. Image acquisition is only using rotary-wing UAV and ground measurements for georeferencing and accuracy testing were conducted using Global Positioning System. This data acquisition method will be described more in next section.

2. Methodology
2.1. Research location
The test site of this research is Kebonwaris Village, District of Pandaan, Pasuruan Regency, East Java. It is located about 60 km from Surabaya to the south and can be reached within 1 hour driving via Surabaya-Malang arterial street or Gempol-Pandaan toll road. The village has mean elevation about +150 m above mean sea level with an area ±167 hectares and ±10 km perimeter and mainly dominated by agricultural land, rural settlements, and vegetation.

Figure 1. Research location (http://maps.google.com)
2.2. Aerial image acquisition
The main instrument for image acquisition is a consumer grade UAV namely DJI Phantom 3. This platform was chosen because of its ease of use in operation. In addition, it has a built-in camera, GPS antenna, and compass. Therefore, the operator can monitor the position, orientation, and image stream from the platform anytime during the flight. The main specifications of this platform is as follows:

![Figure 2. DJI Phantom 3 (www.dji.com)](image)

**Table 1.** DJI Phantom 3 specifications

| Information                      | Description          |
|---------------------------------|----------------------|
| Weight                          | 1280 g               |
| Maximum speed                   | 16 m/s               |
| Maximum flight time             | 23 minutes           |
| Hovering accuracy               | ± 0.5 m              |
| Maximum cruising range          | 3.5 km               |
| Sensor size                     | 1/2.3” CMOS          |
| Image size                      | 4000x3000 pixels     |
| Focal length/35 mm focal length | 4 mm/20 mm           |
| File format                     | JPEG, DNG (raw)      |
| Storage                         | Micro SD card up to 64 GB |

The platform was operated by a pilot and the assistant by manually controlling the movement of the aircraft. Cruising altitude was set to 150 m above ground level and camera shutter was released every 5 seconds. The pilot attempted to achieve at least 80% overlap between images. To ensure sufficient overlap between photos and checking area coverage the pilot must carefully watch the monitor. The assistant helped the pilot to spot the aircraft in the sky and guiding the pilot for landing, since in remote area there is no perfect surface for landing. Due to limited flight time, image acquisition was performed in several missions. Each mission has its own take off and landing spot to optimize image coverage. In this research the total number of acquired images is 2528.
2.3. Ground control measurement
To derive final georeferenced raster image, the presence of Ground Control Point (GCP) is required. The GCPs were established across the study area to ensure same horizontal accuracy of final product in all study area. There were 12 GCPs on the study area. All points were measured using differential Global Positioning System with 5 seconds data interval during at least 30 minutes. This will ensure that the baselines have sufficient data for differential GPS processing. All GCPs final coordinates are presented in UTM Zone 49S with WGS 1984 reference ellipsoid.

![GCP distribution at research area](image)

For GCP identification on the images, a large premark with 1-m length was installed on each GCP. This ensures that the GCPs will be easily identified especially at the places where natural target such as road corners or signs do not exist.

2.4. Image orientation and Georeferencing
The main data processing strategy in this research is Structure from Motion (SfM) approach. This approach is selected because of its ability to reconstruct camera pose and 3D object simultaneously and automatically. The SfM approach can handle many unordered sets of images and doesn’t require regularities in image blocks. Therefore, this method is very suitable for this research since the manual control of UAV unit can result irregularities in image blocks.

Since the UAV has a GPS, the acquired images also have geographic coordinate information. This position data recorded from the UAV can be used to orient the stereo model into approximated absolute
coordinate system. But since the accuracy of GPS data from the UAV hasn’t reached centimetre level, the final georeferencing process must be done based on the GCPs coordinates. In this research, the accuracy of final georeferencing process is 0.030 m. This accuracy is sufficient since the ground sample distance of the raw image is 0.064 m.

2.5. *Photogrammetric restitution*
After the images have been oriented properly in absolute coordinate system, the 3D reconstruction process can be started. In this step the object geometry is reconstructed with higher detail. This process mainly relies on space intersection and digital image matching technique. By knowing the exterior orientation parameters of the images and corresponding image point in other images, the 3D position many points can be determined. To speed up the processing, digital image matching technique only applied along the epipolar lines on other images. The epipolar lines were generated from exterior orientation parameters.

![Figure 5. Dense point cloud](image)

The result of this step is 3D model of research area with fine details. This 3D model represents topographic features such as flat land, inclined land, riverbanks, etc. The high vegetation and manmade features such as building, houses, etc are also presented well. The elevation information of these objects is very important in eliminating relief displacement to produce accurate orthophoto.

2.6. *DSM and orthophoto generation*
The resulting dense point cloud from photogrammetric restitution has represented the 3D appearance of research area. But it is still presented in discrete data that must be interpolated to be 3D surface model. This 3D surface model is essential for Digital Surface Model and orthophoto generation. The 3D surface model is very essential for removing relief displacement.

![Figure 6. Digital Surface Model](image)
Due to various lighting condition and sun elevation, there are several inconsistencies of image brightness in some regions. Higher sun elevation combined with reflective surface such as water bodies can cause strong reflection which makes some flares at final orthophoto. To avoid this, the sun’s reflections on water bodies were excluded in texture blending process.

3. Result and Discussion

3.1. Image acquisition and flight trajectory

This research has acquired totally 2528 images of research area. The redundant images ensure that all area have been covered well. But in further processing some images were filtered out due to blurring and excessive overlap which can slow down the processing and decreasing the image sharpness. Due to manual control of platform’s movement, the resulting image block and flight trajectory becomes irregular. But in terms of image coverage and overlap the resulting images are sufficient enough. All area is covered by at least 4 images.

![Image coverage, overlap, and flight trajectory](image)

**Figure 7.** Image coverage, overlap, and flight trajectory

Flying the platform by relying on pilot’s skill is very difficult in order to get regular image blocks and flight trajectory. Beside that it needs more effort to ensure that all study area has good image coverage and overlap. Notice the area which has less overlap on the north-eastern part of the area. Therefore, in the future the presence of automated flight planning will become more important.

3.2. Orthophoto of research area

Although the ground sample distance is up to 6 cm resolution, the final orthorectified image was rendered at 10 cm resolution for storage and memory efficiency. This orthorectified image covers all area of Kebonwaris Village and has good visual details. There are no significant variations in image brightness. Many appearances of manmade structures have been corrected from relief displacement. Thus, this image is ready for further usage such as map production.
3.3. **Horizontal accuracy analysis**

In order to analyse the horizontal accuracy of orthophoto, the coordinate measurement of some Independent Check Points is required. The check points are distributed across the research area. In this research there are 22 check points whose coordinates are measured by using differential GPS technique with at least 15 minutes observation with 5 seconds data interval. Then, the resulting coordinate from GPS measurement is compared against coordinate measurement from the orthophoto. The distribution of these check points is shown in Figure 9.
The results show that the mean absolute horizontal errors are 0.071 m and 0.142 m for easting and northing respectively. These horizontal errors are ranging from -0.198 m to 0.089 m and from -0.256 to 0.335 for easting and northing respectively. These absolute horizontal errors are corresponding to resultant error 0.170 m. The Root Mean Square Error (RMSE) of easting and northing component are 0.088 m and 0.169 m respectively. These values correspond to horizontal RMSE 0.190 m. Compared to the ground sample distance of raw image, i.e. 0.064 m, the reached RMSE value is 3 times of GSD. This value can be lowered by using pre-calibrated camera sensor for more optimal lens distortion removal.

According to Peraturan Kepala BIG No. 15 Tahun 2014 [10], one of criteria for assessing the horizontal accuracy of mapping product is CE90 criterion. In this document the CE90 criterion is simply defined as:

\[ CE_{90} = 1.5175 \times RMSE_r \]

where \( RMSE_r \) is the overall horizontal Root Mean Square Error. Based on this formula the CE 90 value in this research is 0.289 m. This value is acceptable for making a base map in 1:2500th scale with the best quality (class 1 quality) or a base map in 1:1000th scale with good quality (class 2 quality).
4. Conclusions
In this research the method of large scale mapping for rural map production has been demonstrated. The use of rotary wing UAV could produce acceptable result according to current standard by Badan Informasi Geospatial. By using this method, the horizontal accuracy could reach 0.289 m and it is acceptable for making base map in 1:2500th scale or class 2 base map in 1:1000th scale. Some improvements should be made in order to achieve more efficient process and better results. The use of flight planning becomes very important in order to ensure overall coverage of mapped area. Pre-calibrated camera sensor should be used in next research to achieve an accuracy nearly with desired Ground Sample Distance.

Acknowledgement
Authors would like thank to Lembaga Penelitian dan Pengabdian Masyarakat (LPPM) Institut Teknologi Sepuluh November for supporting the research funding, and also for Geodesy and Surveying Laboratory, and Laboratory of Cadastre and Land Policy for field data acquisition support.

References

[1] Badan Informasi Geospasial. 2016. Peraturan Kepala Badan Informasi Geospasial Nomor 3 Tahun 2016 tentang Spesifikasi Teknis Penyajian Peta Desa. Bogor: Badan Informasi Geospasial.
[2] Eisenbeiss, H. 2009. UAV Photogrammetry. Disertasi. Zürich: Swiss Federal Institute of Technology Zürich
[3] Rokhmana, C. A. 2014. Mapping the Outermost Small Islands Utilizing UAV–Based Aerial Photography. FIG Congress 2014, 16-21 Juni 2014, Kuala Lumpur, Malaysia.
[4] Li, C., dkk. 2011. Quick Image Processing Method of UAV Without Control Points Data in Earthquake Disaster Area. Transactions of Nonferrous Metals Society of China 21 (2011) s523-s528.
[5] Niethammer, U., dkk. 2012. UAV-based Remote Sensing of The Super-Sauze Landslide: Evaluation and Results. Engineering Geology 128 (2012) 2-11.
[6] Seitz, C., dan Altenbach, H. 2011. Project Archeye-The Quadrocopter as The Archaeologist’s Eye. International Archives of Photogrammetry, Remote Sensing, and Spatial Information Sciences, Vol. XXXVIII-1/C22, UAV-g 2011, Conference on Unmanned Aerial Vehicle in Geomatics, Zurich, Switzerland.
[7] Mozas-Calvache, A. T., dkk. 2012. Method for Photogrammetric Surveying of Archaeological Sites with Light Aerial Platforms. Journal of Archaeological Science 39 (2012) 521-530.
[8] Lo Brutto, M., dkk. 2014. UAV Platforms for Cultural Heritage: First Results. ISPRS Annals of Photogrammetry, Remote Sensing, and Spatial Information Sciences, Volume II-5, 2014, ISPRS Technical Commission V Symposium, 23-25 Juni 2014, Riva del Garda, Italia.
[9] Mancini, F., dkk. Using Unmanned Aerial Vehicles (UAV) for High-Resolution Reconstruction of Topography: The Structure from Motion Approach on Coastal Environments. Remote Sensing 2013, 5, 6880-6898; doi: 10.3390/rs5126880.
[10] Badan Informasi Geospasial. 2014. Peraturan Kepala Badan Informasi Geospasial Nomor 15 Tahun 2014 tentang Pedoman Teknis Ketelitian Peta Desa. Bogor: Badan Informasi Geospasial.