Precise topographic mapping using direct georeferencing in UAV

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Abstract. Mapping using UAV has become very popular today due to the rapid development of electronic technology. UAVs are needed to support rapid mapping activities, such as natural disaster management, SAR applications, agricultural applications and forest fire monitoring. In addition to spatial resolution, it is also needed the accuracy of position accuracy. In general, the georeferenced process of aerial photo processing uses Ground Control Points (GCP) from GPS measurements. The disadvantage of using GCP is that GPS measurement takes a long time and the costs incurred are relatively more expensive. For this reason, certain techniques are needed to produce topographic maps with more efficient times. Direct Georeferencing on UAV is an aerial triangulation technique without the use of ground control points (GCP). Direct Georeferencing techniques will cut field surveys and produce high accuracy topographic maps. The hope is that by using this technique, the measurement of tie points can be as minimal as possible and do not even need to use a control point. This study is to evaluate Direct Georeferencing techniques in UAVs to produce accurate topographic map. Aerial photo using multi rotor UAV DJI Phantom 4 RTK/PPK. This multi rotor is equipped with a high accuracy GPS antenna and that is capable to storing GPS observation data. Photo coordinate processing using the Post Processing Kinematic (PPK) method. Accuracy of ortho rectification results of aerial photo geometry compared to check point coordinates (CP). The test results of horizontal accuracy indicate the value of 0.040 m using Circular Error 90% (CE90). Based on BIG standard the accuracy of the base map, these results can be entered on a scale of 1: 1,000 class 1. Direct Georeferencing techniques in UAVs produce high accuracy maps for relatively not extensive mapping areas.

1. Introduction
Mapping using Unmanned Aerial Vehicles (UAV) is becoming very popular nowadays due to the rapid development of positioning (small size GPS with high accuracy position), electronics aviation (autopilot flight control) and sensors. UAV are needed to support rapid mapping activities, such as natural disaster, Search and Rescue applications, forest rehabilitation monitoring [1] , plant identification [2] and forest fire monitoring [3]. UAV can produce a more detailed view of the earth's surface with very good resolution [4] . Aerial photographs with high resolution will facilitate the process of identifying objects for the purposes of large-scale mapping. In addition to spatial resolution, accuracy of position is also required. In general, the process of georeferencing processing using a Ground Control Point (GCP). GCP is a point on the ground whose coordinates are known and used as a reference in the process of aerial triangulation processing.

The disadvantage of using GCP is that GPS measurement takes a long time and costs are more expensive. Another disadvantage of this technique is not all areas can be reached using GPS or inaccessible areas. For this reason, certain techniques are needed to produce topographic maps more time efficient. Direct Georeferencing on UAVs is an aerial photo restitution technique without use of Ground
Control Points (GCP). This technique will reduce field surveys and can produce high accuracy topographic maps.

Unlike Aerial Triangulation, Direct Georeferencing (DG), see Figure 1, is the direct position and orientation measurements of the camera during capturing so, each pixel can be geo-referenced to the Earth coordinate system without any needing for ground information [5]. In Aerial triangulation, antenna GPS records X, Y, Z coordinate and IMU (Inertial Measurement Unit) records orientation angles \( \omega, \varphi, \kappa \) at the time of exposure. These measurements are integrated and form six parameters which are called Exterior Orientation (EO) parameters, that are used in collinearity equation for Georeferencing (6). In a traditional photogrammetry, EO parameters are produced from Aerial Triangulation which needs Ground Control Points distributed regularly. In Direct Georeferencing, exterior orientation parameters are computed from GPS measurement. The error of GPS, time synchronization and offset between GPS and camera may cause errors in linear exterior orientation parameters.

Figure 1. Direct geo-referencing and aerial triangulation concept (5).

The process of producing topographic maps using UAV is faster with Direct Georeferencing techniques. This study aims to evaluate the Direct Georeferencing technique in UAVs to produce large-scale topographic maps. It is hoped that with this Direct Georeferencing technique, measurement of control points in the field can be as minimal as possible.

2. Method

Aerial photography can use various types of UAV such as multi-rotor and fixed wing, in this study the UAV used is DJI Phantom 4 RTK/PPK. The advantage of using a multi-rotor type is that drones can take off and land vertically anywhere. In addition, the multi-rotor type has the ability to carry more capacity, such as DSLR cameras. DJI Phantom 4 RTK/PPK specification can be seen in Table 1. DJI Phantom 4 RTK/PPK drones are equipped with high accuracy GPS antennas. This antenna is able to store dual frequency GPS satellite observations (L1 and L2) which can later be used for post processing purpose. Data interval GPS observations in the Phantom 4 RTK/PPK is every 1 second with the satellite segments used are GPS and GLONASS. In addition, DJI Phantom 4 RTK/PPK is equipped with an RTK module that can be used for real time positioning. Corrections from the base station are sent via radio or internet network (NTRIP RTK method). This study only discusses the determination of the position of the GNSS antenna in the drone Phantom 4 RTK/PPK using the post processing kinematic method. DJI Phantom 4 RTK/PPK carries CMOS type cameras with effective camera resolution up to 20 MP. The specifications of the camera used can be seen in Table 2.
Table 1. DJI Phantom 4 RTK/PPK specification

| Aircraft |                |
|----------|----------------|
| Take-off Weight | 1391 g          |
| Diagonal Distance  | 350 mm          |
| Max Ascent Speed   | 6 m/s (automatic flight); 5 m/s (manual control) |
| Max Descent Speed  | 3 m/s           |
| Max Speed          | 31 mph (50 kph) (P-mode) |
| Max Speed          | 36 mph (58 kph) (A-mode) |
| Max Flight Time    | Approx. 30 minutes |

| GNSS       |                |
|------------|----------------|
| Single-Frequency, High-Sensitivity GNSS Module | GPS+Beidou+Galileo (Asia); GPS+GLONASS+Galileo (other regions) |
| Frequency Used | GPS: L1/L2; GLONASS: L1/L2; Beidou: B1/B2; Galileo: E1/E5a |
| First-Fixed Time | < 50 s        |
| Positioning Accuracy: Vertical 1.5 cm + 1 ppm (RMS); Horizontal 1 cm + 1 ppm (RMS) |
| 1 ppm means the error has a 1mm increase for every 1 km of movement from the aircraft. |

Table 2. Sensor Specification

| Camera |                |
|--------|----------------|
| Sensor | 1" CMOS; Effective pixels: 20 M |
|        | FOV 84°; 8.8 mm / 24 mm |
| Lens   | (35 mm format equivalent:24 mm); f/2.8 - f/11, auto focus at 1 m - ∞ |
| ISO Range | Photo:100-3200(Auto) |
|          | 100-12800(Manual) |
| Mechanical Shutter Speed | 8 - 1/2000 s |
| Electronic Shutter Speed | 8 - 1/8000 s |
| Max Image Size | 4864×3648 (4:3); |
|                  | 5472×3648 (3:2) |
| Photo Format    | JPEG             |
Average altitude in this Aerial photography is 100 meters above ground level, with a total area of 12 hectares, more details area of interest can be seen in Figure 2. The process of acquiring aerial photo data was at the Geospatial Information Agency (BIG) office in Cibinong. Determination of sidelap and overlap of photos by 70% and 80% produces 293 photos. The flight duration in this area around the BIG office takes about 10 minutes. Illustration of drone flying height can be seen in Figure 3.

GPS data processing method is Post Processing Kinematic with a fixed base station CORS BAKO. GPS processing uses precise ephemeris to improve position accuracy. The process of determining phase ambiguity uses a combination filter type (forward and backward). The complete data processing parameters can be seen in the table. The final results of recorded drone coordinates are presented in the format Latitude, Longitude and Height. While the time format uses GPS time that is GPS week and GPS seconds according to the *.MRK file generated from the DJI Phantom 4 RTK/PPK photo. Later the results of this coordinate processing (*.pos) will be interpolated to the recorded aerial photo file (*.MRK).
### Table 3. GPS Processing parameter.

| Parameter                  | Keterangan         |
|----------------------------|--------------------|
| Positioning mode           | Kinematic          |
| Control Point              | CORS BAKO          |
| Frequencies signal         | Dual Frequency     |
| Filter type                | Combined           |
| Elevation Mask (˚)         | 10                 |
| Satellite data interval    | 1 second           |
| Ionosphere Correction      | Broadcast          |
| Troposphere Correction     | Saastamoinen       |
| Satellite ephemeris        | Precise            |
| Satellite segment          | GPS and GLONASS    |
| Integer Ambiguity Resolution| Fix and Hold     |
| Solution Format            | Lat/Lon/Height     |
| Time Format                | ww ssss GPST       |

DJI Phantom 4 RTK / PPK produces 4 files from aerial photography, among others: PPKRAW, event log, RINEX dan timestamp. PPKRAW has the satellite observations in RTCM3.2 MSM5 format, event log has the time log in binary, and RINEX has the GNSS observations. Then, timestamp contains the following, in ASCI:

1. Photo number
2. Exposure time of GPS seconds of the week
3. Exposure time of GPS week
4. Phase compensation between north antenna to CMOS centre (mm)
5. Phase compensation between east antenna to CMOS centre (mm)
6. Phase compensation between up/down antenna (downward is positive) to centre of CMOS (mm)

The position of the camera center is relative to the phase center of the onboard D-RTK antenna under the aircraft body's axis: (36, 0, and 192 mm) already applied to the image coordinates in EXIF data. The positive x, y, and z axes of the aircraft body point to the forward, rightward, and downward of the aircraft, respectively. In this research, we use ASP suite software for lever arm correction, calculate Post Processing Kinematic and geotagging photo from calculate coordinate. We need a base station (CORS BAKO) to correct the position of the GPS antenna on the drone using Post Processing Kinematic method. ASP suite converts the time of the flight trajectory epoch points to GPS seconds and interpolates positions for each photo according to its GPS time of capture. Each photo will be entered precise coordinates of the results of the calculation, which is referred to as geotagging.

### 3. Result and Discussion

The results of ICP point processing can be seen in Table 4. Solution for ambiguity in the control point data processing phase is FIXED. ICP point processing results get horizontal precision results in the range of 0.003-0.005 meters, while vertical precision ranges in the range of 0.004-0.010 meters. Root mean square error results of processing vary in the range 0.003 to 0.052. After the data collection process and photo processing are complete, an orthophoto mosaic is formed in the office area of the Geospatial Information Agency. The final output is producing aerial photographs with a GSD (Ground Sampling Distance) value of 3 cm / pixel. GSD is a spatial resolution used to determine the quality of the resulting
aerial photography. GSD 3 cm / pixel means that the smallest object that can be recognized is 3 centimetres.

Table 4. ICP point processing results

| ID   | Easting (Meter) | Northing (Meter) | Elevation (Meter) | H. Prec. | V. Prec. | RMS   | Solution |
|------|-----------------|------------------|-------------------|----------|----------|-------|----------|
| 0001 | 704547,193      | 9282162,589      | 139,013           | 0,003    | 0,008    | 0,005 | FIXED   |
| 0002 | 704496,691      | 9282174,686      | 138,911           | 0,005    | 0,010    | 0,052 | FIXED   |
| 0003 | 704464,411      | 9282139,283      | 139,284           | 0,003    | 0,005    | 0,003 | FIXED   |
| 0004 | 704464,015      | 9282058,255      | 139,292           | 0,005    | 0,008    | 0,008 | FIXED   |
| 0006 | 704491,027      | 9282291,607      | 142,679           | 0,004    | 0,004    | 0,006 | FIXED   |
| 0007 | 704512,066      | 9282280,966      | 142,816           | 0,004    | 0,004    | 0,003 | FIXED   |
| 0008 | 704511,912      | 9282290,402      | 142,611           | 0,004    | 0,004    | 0,002 | FIXED   |
| 0010 | 704463,069      | 9282218,256      | 146,921           | 0,004    | 0,005    | 0,003 | FIXED   |
| 0011 | 704475,117      | 9282195,801      | 146,982           | 0,004    | 0,005    | 0,002 | FIXED   |
| 0012 | 704457,362      | 9282197,939      | 143,104           | 0,004    | 0,006    | 0,006 | FIXED   |
| 0013 | 704462,628      | 9282189,168      | 143,166           | 0,004    | 0,005    | 0,006 | FIXED   |

After the data collection process has been carried out and the photo processing is complete applied to the entire photo, a mosaic image of the mapped area is formed. The results of the dense cloud formation can be seen in Figure 4. The process of forming point clouds is by identifying the points that have the same pixel value.

Figure 4. The results of dense cloud.
Figure 5. The result of the build mesh

3-dimensional mesh reconstruction is a representation of the surface of an object formed based on the dense point cloud. Mesh formation is done to build a 3-dimensional texture of the photo. After the geometry is formed, the mesh is used to make orthophoto. The results of the build mesh can be seen in Figure 5.

Figure 6. The result of DEM
3.1. Evaluate the geometric accuracy of aerial photo mosaics

Geometric accuracy is a value that describes the uncertainty of object position on an orthophoto mosaic compared to the position of an object that is considered to be its true position. The accuracy of the geometry tested is on horizontal and vertical. Evaluation of aerial photo mosaics is done by comparing the coordinates of aerial photographs with the coordinates of GPS data processing results. Position accuracy testing refers to the difference in coordinates (X, Y) between the test points on the orthophoto mosaic and the actual location on the ground surface. Measurement of accuracy using Root Mean Square error (RMSE) and Circular Error. RMSE is used to describe accuracy including random and systematic errors. RMSE value can be seen in Equation 1.

\[
RMSE_{\text{horizontal}} = \sqrt{\frac{\sum (x_{\text{data}}-x_{\text{cek}})^2 + (y_{\text{data}}-y_{\text{cek}})^2}{n}}
\]

Information:

\(n\) = The total number of test points on the map
\(x\) = coordinate values on X-axis
\(y\) = coordinate value on Y-axis

The orthophoto mosaic position accuracy value is CE90 for horizontal accuracy, which means that the position error in the orthophoto mosaic does not exceed the accuracy value with a 90% confidence level. Calculation of CE90 values can be seen in Equation 2.

\[CE90 = 1.5175 \times RMSE_{r}\]

Information:

\(RMSE_{r}\) = Root Mean Square Error in position x and y (horizontal)

Geometry Accuracy based on BIG Head Regulation no. 6 about Amendment to the BIG Head regulation No. 15 of 2014 about technical guidelines for the accuracy of the base map (2018). The geometry accuracy of topography map (RBI) is shown in Table 5.

| No | Scale       | Contour interval (m) | Accuracy of the Base Map (m) | Class 1 | Class 2 | Class 3 |
|----|-------------|----------------------|------------------------------|---------|---------|---------|
|    |             |                      | Horizontal (CE90)          | Vertical (LE90) | Horizontal (CE90) | Vertical (LE90) | Horizontal (CE90) | Vertical (LE90) |
| 1. | 1:50.000    | 20                   | 15                           | 10      | 30      | 15      | 45      | 20      |
| 2. | 1:25.000    | 10                   | 7,5                          | 5       | 15      | 7,5     | 22,5    | 10      |
| 3. | 1:10.000    | 4                    | 3                             | 2       | 6       | 3       | 9       | 4       |
| 4. | 1:5.000     | 2                    | 1,5                           | 1       | 3       | 1,5     | 4,5     | 2       |
| 5. | 1:2.500     | 1                    | 0,75                          | 0,5     | 1,5     | 0,75    | 2,3     | 1       |
| 6. | 1:1.000     | 0,4                  | 0,3                           | 0,2     | 0,6     | 0,3     | 0,9     | 0,4     |

In addition to spatial resolution, another thing that is no less important is the geometry accuracy of the resulting aerial photography. The process of processing aerial photography is done by inserting photos that already have the coordinates of the results of the PPK process (DG method) and photos without the PPK process. Evaluation of the accuracy of the aerial mosaic of aerial photographs using PPK coordinates can be seen in Table 6, while the accuracy of the geometry without the PPK process can be seen in Table 7.
Table 6. Horizontal accuracy test results use the Direct Georeferencing method.

| ID point | Ortho Result | Field Measurement | DX Meters | DY Meters | $DX^2$ | $DY^2$ | $DX^2 + DY^2$ |
|----------|--------------|-------------------|-----------|-----------|--------|--------|---------------|
| X Orto   | Y Orto       | X Measurement     | Y Measurement |         |        |        |               |
| I001     | 704547.197   | 9282162.60        | 704547.193 | 9282162.589 | 0.044  | 0.019  | 0.001         |
| I002     | 704496.717   | 9282174.68        | 704496.691 | 9282174.686 | 0.026  | 0.001  | 0.001         |
| I003     | 704464.417   | 9282139.28        | 704464.411 | 9282139.283 | 0.006  | 0.003  | 0.000         |
| I004     | 704464.043   | 9282058.27        | 704464.015 | 9282058.255 | 0.028  | 0.015  | 0.000         |
| I006     | 704491.026   | 9282291.60        | 704491.027 | 9282291.607 | -0.001 | 0.002  | 0.000         |
| I007     | 704512.101   | 9282280.97        | 704512.066 | 9282280.966 | 0.035  | 0.010  | 0.001         |
| I008     | 704511.925   | 9282290.39        | 704511.912 | 9282290.402 | 0.013  | -0.009 | 0.000         |
| I010     | 704463.088   | 9282195.80        | 704463.069 | 9282195.256 | 0.019  | -0.010 | 0.000         |
| I011     | 704475.125   | 9282197.92        | 704475.117 | 9282195.801 | 0.008  | 0.007  | 0.000         |
| I012     | 704457.396   | 9282189.15        | 704457.362 | 9282197.939 | 0.034  | -0.010 | 0.001         |
| I013     | 704462.661   | 9282218.15        | 704462.628 | 9282189.168 | 0.033  | -0.011 | 0.000         |
|          | Total        |                   |           |           | 0.007  |        |               |
|          | Variance     |                   |           |           | 0.001  |        |               |
|          | STD          |                   |           |           | 0.025  |        |               |
|          | Accuracy     |                   |           |           | 0.038  |        |               |

Table 7. Horizontal accuracy test results without the PPK process.

| ID point | Ortho Result | Field Measurement | DX Meters | DY Meters | $DX^2$ | $DY^2$ | $DX^2 + DY^2$ |
|----------|--------------|-------------------|-----------|-----------|--------|--------|---------------|
| X Orto   | Y Orto       | X Measurement     | Y Measurement |         |        |        |               |
| I001     | 704547.899   | 9282165.04        | 704547.193 | 9282162.589 | 0.706  | 2.460  | 6.052         |
| I002     | 704498.915   | 9282176.64        | 704496.691 | 9282174.686 | 2.224  | 1.959  | 4.383         |
| I003     | 704467.969   | 9282142.17        | 704464.411 | 9282139.283 | 3.285  | 2.890  | 10.791        |
| I004     | 704468.215   | 9282064.37        | 704464.015 | 9282058.255 | 4.200  | 6.117  | 17.640        |
| I006     | 704493.054   | 9282290.92        | 704491.027 | 9282291.607 | 2.027  | -0.678 | 4.109         |
| I007     | 704513.997   | 9282280.46        | 704512.066 | 9282280.966 | 1.931  | -0.501 | 3.729         |
| I010     | 704465.641   | 9282218.71        | 704463.069 | 9282218.256 | 2.572  | 0.461  | 6.615         |
| I011     | 704477.608   | 9282196.91        | 704475.117 | 9282195.801 | 2.491  | 1.112  | 6.205         |
| I012     | 704460.246   | 9282198.83        | 704457.362 | 9282197.939 | 2.884  | 0.891  | 8.317         |
| I013     | 704465.519   | 9282190.39        | 704462.628 | 9282189.168 | 2.891  | 1.222  | 8.358         |
|          | Total        |                   |           |           | 131.315| 3.624  | 5.499         |
|          | Variance     |                   |           |           | 13.131 |        |               |
|          | STD          |                   |           |           | 3.624  |        |               |
|          | Accuracy     |                   |           |           | 5.499  |        |               |
From the results of the geometric evaluation the value of horizontal accuracy using the DG method obtained an accuracy of 0.038 meters. This value is smaller than the lowest threshold value of 0.30 meters so that it refers to Table 4, then the value meets the accuracy of the geometry and can be used for map making at a scale of 1: 1,000 class 1. Other results without using precise coordinate from PPK process (absolute position from satellite) get accuracy of 5,499 meters. In accordance with Table 4, these values meet the accuracy of the geometry and can be used for map making at a scale of 1: 25,000 class 1. Mapping aerial photographs using Direct Georeferencing techniques can be used to produce Geospatial Data at a large-scale level.

4. Conclusion
Based on the calculation results of ICP accuracy evaluation according to the geometry accuracy test procedure that refers to the BIG Statement regarding Accuracy of Base Maps with a 90% confidence level for horizontal accuracy (CE90) obtained horizontal accuracy values 0.038 meters for Direct Georeferencing method. From the results of calculations that have been done it can be concluded that the Direct Georeferencing method can meet the accuracy of horizontal geometry at a scale level of 1: 5000 class I. Direct Georeferencing method reduces the use of GCP while still producing high-precision Geospatial Data. Direct Georeferencing techniques in UAVs produce high accuracy maps for relatively not extensive mapping areas.

5. Acknowledgments
Authors wishing to acknowledge to PT GPSlands Indosolutions for support drone Phantom 4 RTK/PPK and ASP suite software. The author also thanks to Geospatial Information Agency for CORS data.

6. Reference
[1] Hird JN, Montaghi A, McDermid GJ, Kariyeva J, Moorman BJ, Nielsen SE, et al. Use of unmanned aerial vehicles for monitoring recovery of forest vegetation on petroleum well sites. Remote Sens. 2017;9(413).
[2] Syetiawan A, Haidar M. Smallholder Oil Palm Plantation Mapping from Non-metric Aerial Photography Using Object-based Analysis. Maj Ilm Globe. 2019;21(1):53–62.
[3] Ambrosia VG, Wegener SS, Sullivan D V., Buechel SW, Dunagan SE, Brass JA, et al. Demonstrating UAV-Acquired Real-Time Thermal Data over Fires. Photogramm Eng Remote Sens. 2003;69(4):391–402.
[4] Syetiawan A, Gularso H. Pembentukan DSM Menggunakan Unmanned Aircraft System (UAS) dan Kamera Digital Non Metrik. In: Seminar Nasional Geografi dan Pembangunan Berkelanjutan. 2018. p. 410–24.
[5] Rabah M, Basiouny M, Ghanem E, Elhadary A. Using RTK and VRS in direct geo-referencing of the UAV imagery. NRIAG J Astron Geophys [Internet]. 2018;7:220–6. Available from: https://doi.org/10.1016/j.nrjag.2018.05.003
[6] Cramer M, Stallmann D, Haala N. Direct geo-referencing using GPS/inertial exterior orientations for photogrammetric applications. Int Arch Photogramm Remote Sens. 2000;33(B3):198–205.